THE APPLICATION OF ELECTRICITY AND MAGNETISM TO TRANSMISSION IN THE TELEPHONE PLANT

SECTION II

ELEMENTARY PRINCIPLES—ALTERNATING CURRENTS

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SECTION II

ELEMENTARY PRINCIPLES— ALTERNATING CURRENTS

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SECTION II

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ELEMENTARY PRINCIPLES—ALTERNATING CURRENTS

SECTION II-A

NATURE OF ALTERNATING CURRENTS

PART I

ALTERNATING VOLTAGE—INDUCTANCE—CAPACITY

Alternating Voltage

The circuits thus far considered in Section I have for the most part consisted of a battery connected to one or more resistances. In such circuits there is always a steady current flow in one direction only and we speak of this current as "direct current" to distinguish it from another kind known as "alternating current." In any one of these circuits we could have reversed the direction of current flow by interchanging the poles of the battery, as shown

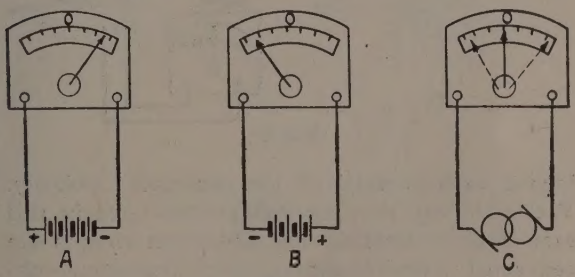


Fig. 1

in Figure 1, but after having done so the current would again become steady and would have the same value in amperes when measured flowing in either direction.

If instead of the battery we had used a small magneto ringing generator such as that mentioned in Section I-F and shown here by Figure 2, we would have had a source of voltage which would tend to establish a current first in one direction and then in the other and continue these reversals as long as the armature revolves. Figure 2 shows such a generator connected to a galvanometer with

a zero center scale. When the generator is turned very slowly the needle will vibrate back and forth between a given reading on the right of the scale and a similar reading on the left of the scale, fol-

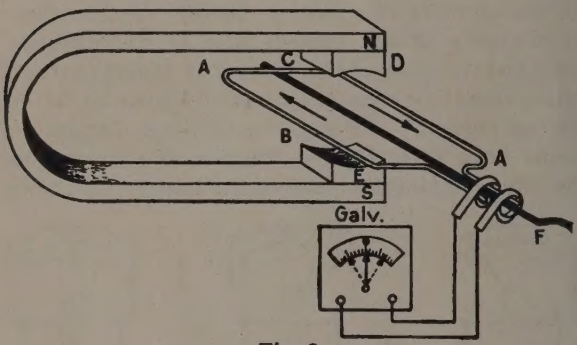


Fig. 2

lowing each reversal of the generator's polarity. We might say that the voltage generated in this case is an alternating one, and when circuits are connected to devices generating an alternating voltage, they may be classed as **"alternating current circuits."**

It will be of interest at this point to see how an alternating voltage is generated. We know from Section I-F that, if the wire indicated in cross-section by the circle in Figure 3-A is moved horizontally to the right, cutting the lines of force which have a downward direction as shown, a voltage will be generated in the conductor. The direction of this voltage, and the circular field set up around the conductor by a current in this direction, must be as shown in Figure 3-B. This is necessary because the two fields must react to exert upon the conductor

a force opposing the generating motion. Were the voltage in the opposite direction the circular field and the reacting force would be reversed, and we would then have perpetual motion—a motor generating the power to drive itself—which is absurd.

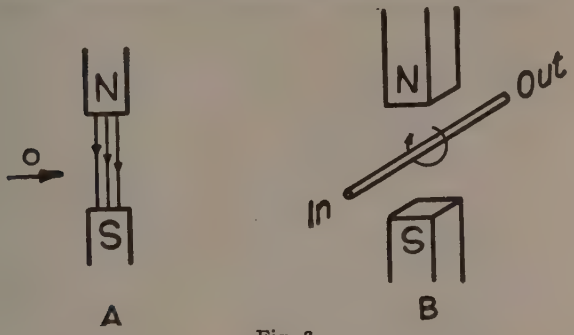


Fig. 3

Figure 4 depicts an easily remembered rule, called the "right-hand rule," for determining the direction of any induced emf. The forefinger of the right hand represents the direction of the lines of force leaving a north pole and entering a south pole; the

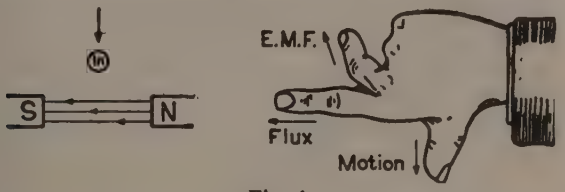


Fig. 4

thumb, when pointed perpendicular to the forefinger, represents the direction in which the conductor moves; and the second finger, when perpendicular to both the forefinger and the thumb, gives

the direction of the induced voltage or the direction of current flow.

If now a galvanometer of the direct current reading type is connected to the conductor illustrated in Figures 3 and 4, as shown in Figure 5, the presence of a voltage between the two ends of the conductor as it breaks or cuts the lines of force

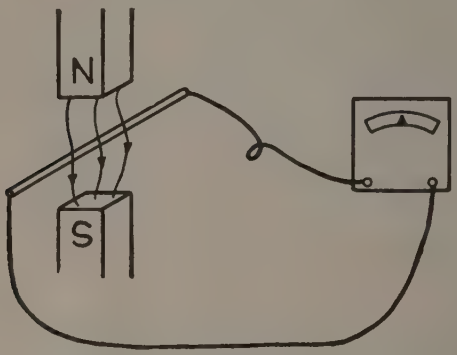


Fig. 5

can be detected by means of the galvanometer reading. Furthermore, it may be noticed that the reading is greater when the conductor is moved swiftly. From these experiments and the scientific manner in which the units for measuring electrical quantities were selected, it is possible to deduce a law covering an induced electromotive force and this law is stated below:

When any conductor is moved so as to cut lines of force (or when lines of force in motion are made to cut any conductor) there will be a voltage induced in the conductor, and the direction of voltage, the direction of flux and the direction of the motion of the conductor with respect to the lines of force

have a perpendicular relation, as given by the right-hand rule. The amount of the induced E.M.F. depends upon the rate of cutting the lines of force or the number of lines cut per second, and if a single conductor cuts 100,000,000 lines of force per second, one volt is induced.

Let us now refer to Figure 6 which shows instead of a single conductor cutting the lines of force, one side of a loop moving in one direction and the other side of a loop moving in the other direction, which

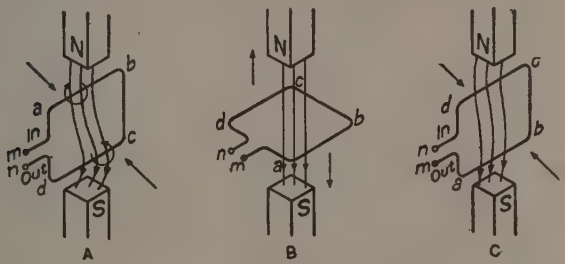


Fig. 6

is in fact a conductor in the form of a revolving loop. With the loop revolving in a clockwise direction, as indicated by the motion arrows, the voltage induced in that part of the conductor between **a** and **b** tends to make a current flow in an opposite direction from the voltage induced in that part of the conductor between **c** and **d** inasmuch as when we apply the right-hand rule to the two sides of the loop we have the motion reversed for the lower part of the loop, while the directions of the lines of force are the same in both cases. This means, however, that the induced voltages will add and the currents established by them will tend to circulate in the loop in the same direction.

If we follow the motion of the loop through a complete revolution we shall find that it is cutting the lines of force fastest when in position **A**, and that it is not cutting any lines of force at all in the position **B**, inasmuch as both sides are moving parallel to and not across the direction of the lines of force. In position **C** it is again cutting lines of force at the maximum rate, but this time in the reverse direction with respect to direction of flow in the loop, and, therefore, the current circulating in the loop must have reversed its direction, which accounts for the so-called cycle of alternating flow.

Now if the terminals of the loop **m** and **n** are connected to two separate rings and these are in turn mounted on a shaft carefully insulated from it and with brushes arranged to slide on the rings, we have an alternating current generator in its simplest form. We shall find, however, that a single loop would give us a very weak voltage and in practice, therefore, there is a continuous winding of several loops which multiplies the value of the generated voltage by the number of turns. This is illustrated in the case of the small magneto ringing generator by Figure 2.

The revolving element of an alternating generator is called its armature. The range of voltage values begins at zero when the armature actually is perpendicular to the field (Figure 6-B) and reaching a maximum value in one direction when the plane of the armature is parallel with the field (Figures 6-A and 6-C); again sweeps through another zero point at ½ revolution to reach a maximum value at ¾ths revolution with the voltage reversed with respect to the generator's brushes, and again decreases to zero at a full revolution where

the cycle repeats itself. The actual wave form of a true alternating current is shown by Figure 7. It has been given the name "sine wave." Here again

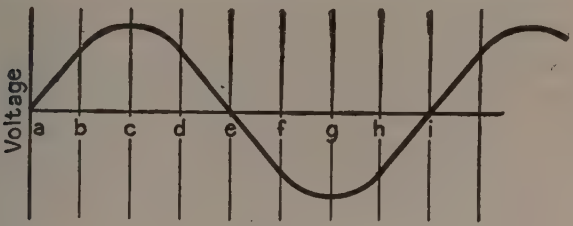


Fig. 7

we have an application of a charted curve. (See supplement to this section for discussion of curves in general.) The horizontal distances measured along the zero line indicate time, and from the points a to i we have that time which is required for one complete alternating cycle which in the case of the magneto generator is about 1/16th of a second, but in the case of other generating devices used in the telephone plant may be as short as 1/1000th of a second. This complete time, of course, is that required for one complete revolution of the generator's armature. The distances measured from the zero line along the vertical lines represent voltage values at the particular instant or at the particular angle of rotation of the armature. In order that we may indicate the reversal in direction of voltage, which would naturally make the current in the circuit reverse its direction of flow, we have plotted both up and down from the zero line calling the flow in one direction minus and that in the other direction plus. Minus here does not mean absence of current flow or lack of current flow, but is merely a convention indicating flow in

a direction other than a chosen direction which is called "positive" in the same way that the minus pole of a battery indicates opposite in electrical nature from the "positive" pole. It should not be assumed that the generator is the only method of creating an alternating voltage. In one sense the telephone transmitter is an alternating current generator, and there are numerous other devices for creating an alternating E.M.F. other than those depending upon a loop of wire revolving in an electromagnetic field.

An alternating voltage is not measured by the number of volts its maximum value, either positive or negative, may attain during the cycle. It is measured by comparing it to a direct voltage that will give the same lighting effect when connected to a lamp or the same heating effect when connected to a heating device consisting of resistance only. It works out that the number of volts when so measured is only approximately 70% as great as the maximum or peak voltage reached during the cycle.

Alternating current circuits are very common in the telephone plant. For some uses they are very efficient, and for that reason they are frequently employed. Alternating current circuits, however, are more complicated than direct current circuits, and special instruments are required to measure the current or the voltage; moreover, the Wheatstone bridge unless modified will not measure the apparent resistance of a circuit to the flow of alternating currents.

We have already mentioned a case where direct current and alternating current are equally efficient and this case is illustrated by Figure 8. Here a

low voltage lamp is connected to a battery of 10 volts. The lamp burns at a definite brilliancy due to the current flow which may be determined by

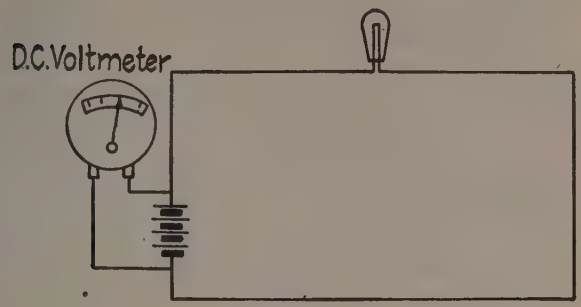


Fig. 8

dividing 10 volts by the resistance of the lamp. We have said that if any alternating current generator of the same effective voltage (and having low internal resistance) is connected to the lamp as in

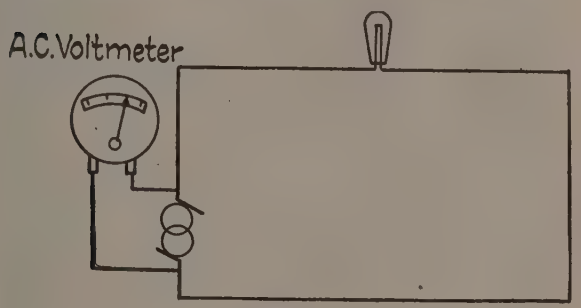


Fig. 9

Figure 9, there will be no change in its brilliancy because this is the way we measure the alternating voltage. The current will be the same in both

cases, and the lamp is said to have the same resistance to the flow of alternating current as to the flow of direct current. In both cases this current can be calculated by Ohm's Law.

In the foregoing assumption, however, we must observe that there are no relay windings or similar coils in series with the lamp and no condensers in any way associated with the lamp circuit. We shall find that **Ohm's Law applies practically the same to alternating current circuits as to direct current circuits when such circuits have resistance only—that is to say, when there are no condensers or windings with iron cores such as relays or other forms of magnets associated with the circuit.**

Inductance

Figure 10 shows a comparison between current flow through the lamp in the above experiment when a coil having resistance but no iron core is

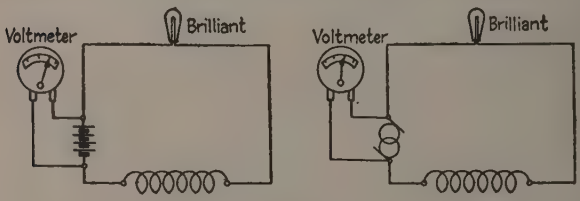


Fig. 10

inserted in series with the lamp. The insertion of the series resistance may slightly decrease the current through the lamp with an accompanying reduction, probably slight, in the lamp's brilliancy, but the strength of the current and brilliancy of the lamp is practically the same in the alternating current case as in the direct current case. But if

an iron core is inserted in the coil, as shown by Figure 11, there will be no change in the lamp's brilliancy for the direct current case, but the lamp will burn noticeably dimmer for the alternating

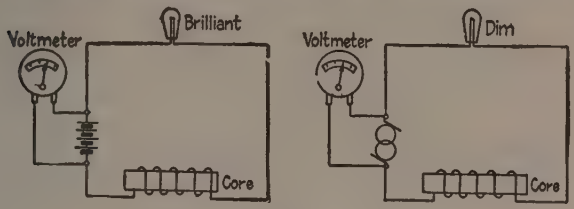


Fig. 11

current case. The iron core has decreased the strength of the current in the latter case, and we may erroneously conclude that this reduction is due to increasing the resistance of the circuit. If, however, the resistance of the coil is measured by the Wheatstone bridge it will be found to be the same either with or without the core. We find, then, that in the alternating current case the coil has some property other than resistance that influences the current flow, and it seems that Ohm's Law does not hold for this circuit. This additional property is called "inductance." It is always present, but in circuits having a steady flow of direct current has no effect. It is immediately brought into play, however, when the current value begins to change, and such a change is always taking place in an alternating current circuit where the current becomes a maximum in one direction to gradually decrease to zero and become a maximum in the other direction, etc. As has been explained in Section I-F, this property is due to the lines of force established in one turn which cut each and every turn of the coil, the number of such lines being

multiplied many times when a core is inserted in the coil. Here induced current is established due to the current being an alternating one instead of a direct current "starting" or "stopping." The induced current in combining with that flowing from the generator will to a degree subtract from it and thereby lessen its value. Thus it is that inductance seems to increase the number of ohms because it lessens the current that will flow for any given alternating e.m.f. The effect is similar to that produced in a direct current circuit when the resistance is increased, thereby lessening the current flow.

Capacity

In addition to inductance there is another property of a circuit that may combine in a peculiar way with the resistance to regulate the current flow. This other property, which we call "capacity" has to do with the circuit's ability to store quantities of electricity. When a circuit has capacity, it will store a quantity of electricity whenever a voltage is connected across it, and the greater the voltage the greater will be the quantity stored. However, the electricity will stay in the circuit only for a short time unless kept there by the electric pressure or voltage. For instance, if we store a certain amount of electricity in a circuit by connecting a voltage to it, and then reduce the voltage, some of the stored electricity will flow out. The amount that will flow out depends on how much the voltage is reduced.

Figure 12 shows a long cable pair open at the distant end connected to a direct voltage and an alternating voltage in the same way that the coil is connected in Figure 11. In the direct current

case with the exception of a kick when the circuit is closed, the ammeter needle stands at zero, indicating no current flow, but in the alternating current case the ammeter gives a definite reading, indicating that the open cable pair has provided a

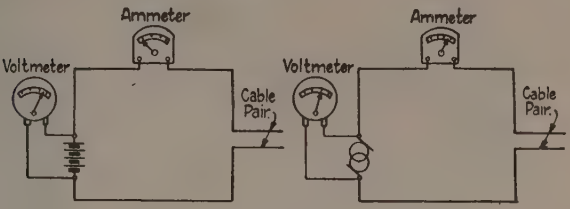


Fig. 12

path for the alternating current. The cable pair is storing electricity, and in the direct current case there is no current flow after the conductors become charged because there is no change in the voltage connected to the circuit. In the alternating current case, however, the voltage is continually changing, since the generator is reversing its polarity at each half cycle. An electric current consequently flows first in one direction and then, when the voltage starts to decrease after reaching its maximum value, in the opposite direction. This current flow is an alternating current, and the circuit is similar to that illustrated by Figure 13 where a condenser is substituted for the cable pair. Here again the action is the same; the voltage first stores electricity in the condenser, then, as the voltage is reduced the condenser discharges, whereupon, the voltage increasing in the opposite direction, the condenser again is charged, but now in the opposite direction. The alternating current es-

tablished in the circuit through the ammeter in series with the condenser is just as true an alternating current as that established through the coil in series with the lamp.

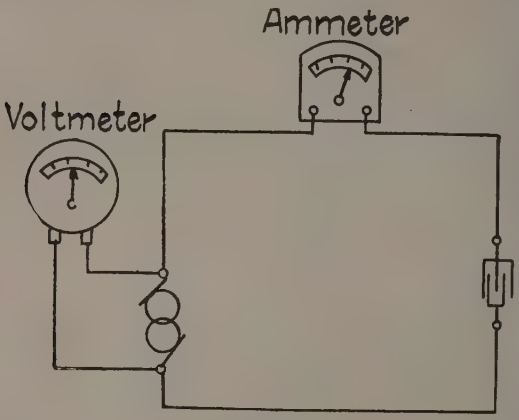


Fig. 13

ELEMENTARY PRINCIPLES— ALTERNATING CURRENTS

SECTION II-A

NATURE OF ALTERNATING CURRENTS

PART II

INDUCTANCE AND CAPACITY

Nature of Inductance and Capacity

From the simple experiments with coils and the cable pair we have seen that in alternating current work we must deal with three physical properties of a circuit instead of one; in other words, we must deal with resistance, inductance and capacity instead of with resistance alone. We have seen that series inductance acts in an alternating current circuit as though it were made up of ohms, yet the physical nature of **inductance** is entirely different from **resistance** and, further, it may be said that the physical nature of **capacity** is entirely different from either **resistance** or **inductance.**

Taking the case of inductance first, it tends to give the circuit something which is analogous to inertia. If no current is flowing in the circuit it tends to oppose or slow down the building up of the current, and when the current is once established it tends to oppose or slow down a dying out of the current. Here we might say that a voltage tending to establish the current in a circuit having inductance is analogous to a force endeavoring to move a heavy body. When the force first exerts itself the body is at rest, and due to the inertia of the body it will take some time for the force to accelerate it to an appreciable speed; the heavier the body the longer the time required for the force to accelerate it. Similarly, if the body is in motion it will resist any force tending to stop it, and the heavier the body the greater will be this resistance and the longer will be the time required for it to be brought to rest. We shall learn later that inductance does actually create voltage within itself (called induced voltage), acting in an opposite direction to the current flowing through it,

whenever there is any change in this current. In other words, the inductance has reacting effects upon a change of current flow, just as the heavy inert body exerts a reacting force upon the applied force tending to set it in motion or to stop it after it has been set in motion.

Capacity, on the other hand, is analogous to the mechanical property called "elasticity"—electricity stored in a condenser acts like a spring under compression. The greater the force applied to a spring, or the voltage applied to a condenser, the greater is the energy stored. When the force is removed a spring tends to recoil; and, if it is free to move, its inertia may keep it moving beyond its normal position, in which case, due to the combined effects of its elasticity and inertia, it will vibrate back and forth in coming to rest. Similarly, if a condenser is discharged through a circuit having inductance, and the resistance in the circuit is low enough, the discharging current will oscillate with diminishing amplitude until the stored energy is completely dissipated.

The manner in which capacity and inductance may be combined so as to neutralize each other's effects, or so as to sustain the oscillating current, which we shall discuss later under the heading of resonant effect, is analogous to the inertia of the rim of a wheel revolving around an axis with a spiral spring connected to it as is the case of the spring and the balance wheel in the ordinary watch. Such a mechanism is illustrated by Figure 14, but let us assume that this particular mechanism is several hundred times larger than the ordinary balance wheel of a watch and more nearly the size of the flywheel of some hand-driven machine. First, let

us assume that the spring is omitted and instead we have spokes in the wheel and there is a crank connected to the shaft. If we take hold of the crank and apply force tending to revolve the wheel speedily we shall find that, due to its inertia, the wheel resists being so revolved, but after the force

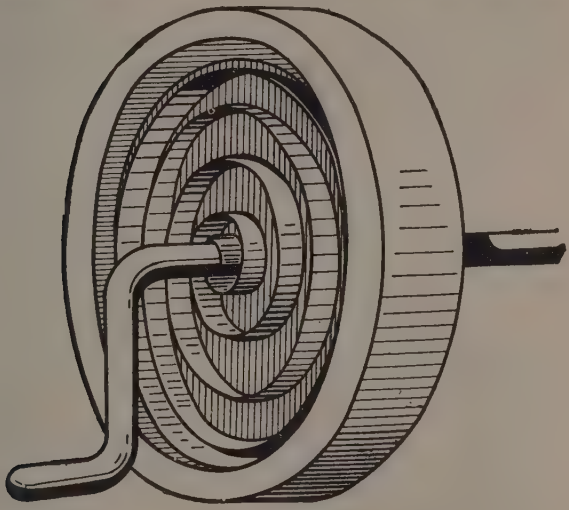


Fig. 14

is applied for a definite time it will acquire this speed. If we should then endeavor to apply a force to the crank to stop the rotation, the wheel would resist being stopped. Now, let us assume the arrangement as shown with the coil spring. As we apply the force to the wheel, although it may resist as before, the resistance will not prevent the rotation of the crank because the elasticity of the spring will permit it to wind and later overcome the inertia of the wheel. The same will apply at stop-

ping. We can stop the crank instantly if we wish, and the inertia of the wheel will be taken up by the elasticity of the spring. Here the rotation of the shaft is analogous to current flowing under the conditions of pure resistance; the rotation of the wheel is analogous to current flow in a circuit having inductance and the coiling and recoiling of the spring is analogous to the current flowing in and out of a condenser. We shall later see how this same device will give us a physical picture of what is known as "resonance."

Units of Inductance and Capacity

From the foregoing experiments we learn that while a direct current circuit is made up of one or more resistances, an alternating current circuit may be made up either of resistance, inductance, capacity or of a combination of these. In the telephone plant coils having inductance are sometimes called **retardation coils.** They oppose the alternating current flow, but do not appreciably affect the direct current flow. A retardation coil's inductance is measured in **henrys,** and the more turns such a coil has the greater the number of henrys. If the core is iron and further if the iron is in the form of a ring, making a closed magnetic circuit, the number of henrys is increased. The inductance in henrys of two retardation coils in series is the sum of their individual inductances in the same way that the total resistance of two resistances in series is the sum of the individual resistances. See Figure 15. Furthermore, the combined inductance of two retardation coils in parallel can be calculated in the same way as resistances in parallel. See Figure 16. This relation of series and parallel inductances

can be proven by an experiment like that illustrated by Figure 17. Here if a second retardation coil is inserted in series the ammeter reading is lowered,

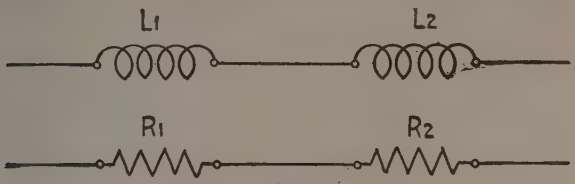


Fig. 15

just as the current is lowered in a direct current circuit when an additional resistance is inserted in series. But if the second retardation coil is connected in parallel with the first, the ammeter read-

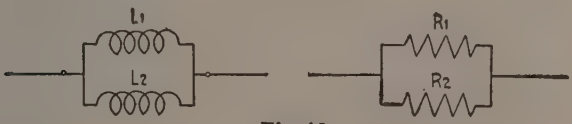


Fig. 16

ing is increased just as the current is increased by lowering the resistance of a direct current circuit.

Capacity as its name implies is ability to store electricity and as the capacity is increased the greater is the amount of electricity that can be

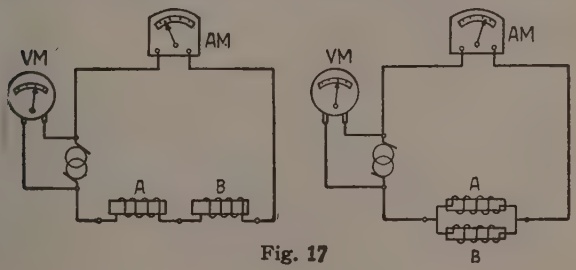


Fig. 17

stored. Storing electricity is in many ways similar to storing gas, and just as in storing gas we increase our pump pressure to store more gas in a given container, so we increase the electric voltage to store more electricity in a given capacity. It follows then that an increased e.m.f. should give an increased current flow through (or rather into) a condenser in the same way that an increased e.m.f. gives an increased current flow through a resistance or inductance. On the other hand, unlike resistance or inductance, an increased capacity gives a greater current flow for the same e.m.f. since a greater quantity of electricity must surge to and fro to charge the condenser.

If in Figure 12 the length of the cable pair is increased we shall find the current through the ammeter will be increased. The quantity of electricity stored by the cable pair at each alternation has been increased. It is obvious that the cable pair can store more electricity than before, and that this greater quantity will increase the current flow first in one direction and then in the other through the ammeter. We can say, then, the capacity depends upon the length of the cable pair or if instead of long conductors we have plates as is the case with the condenser in Figure 13, we can say the capacity depends upon the area of the plates. Large plates will store a greater quantity of electricity than smaller plates.

Now if again in Figure 12 we substitute for the cable pair an open wire circuit of the same length and resistance, we shall find the current flow greatly decreased, indicating lower capacity. This is due to the conductors or plates being further apart, and we find that the capacity of any condenser depends upon the separation of the plates.

When two similar condensers are placed in parallel we have in effect doubled the area of the plates of a single condenser, and we can say, therefore, that capacity in parallel adds like resistance in series.

When two similar condensers are placed in series the middle plates are merely short-circuited together and disconnected from any source of alternating voltage. These are in a sense neutral in the condenser's action, and the others or the active plates would have the same effect as a single condenser with the separation of its plates increased by doubling the thickness of the insulating medium between the plates. From this we reason that condensers in series have lower capacity than that of either condenser, and that the combined capacity of **series condensers** is **calculated like the combined resistance** of **parallel resistances.**

The established unit for measuring capacity is the **microfarad** and from the foregoing it may be

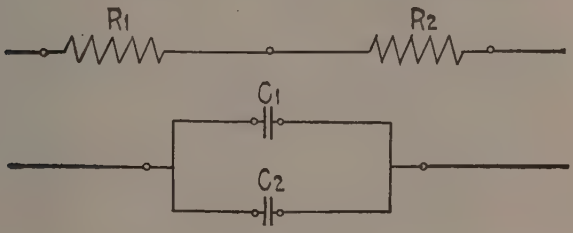


Fig. 18

stated that the capacities of **condensers in parallel add like inductances or resistances in series, and capacities in series add like inductances or resistances in parallel.** See Figures 18 and 19. This rule should be remembered and will be understood by

considering wherein the nature of capacity is different from inductance or resistance with respect to current flow. We shall learn later when we consider the combined effects of capacity and in-

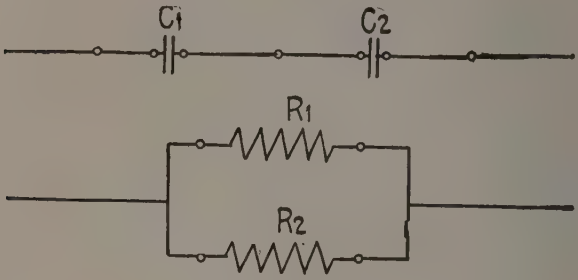


Fig. 19

ductance that the nature of capacity is in other respects opposite to that of inductance.

An application of the above rule may be made by finding the combined capacity of the condenser combination shown in Figure 20.

The capacity from **B** to **C** is equal to .5 + 2 or 2.5 mf.

The capacity from **A** to **C** is equal to .9 times 2.5 or 2.25 divided by .9 plus 2.5 or 3.4 which may be expressed 2.25/3.4 which equals .662 mf.

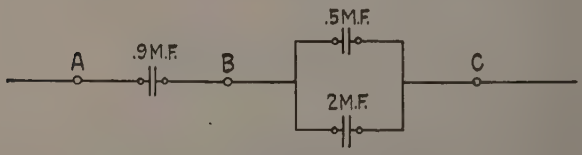


Fig. 20

ELEMENTARY PRINCIPLES— ALTERNATING CURRENTS

SECTION II-B

REACTANCE AND IMPEDANCE

Effect of Capacity and Inductance Depend Upon Frequency

The effect that inductance or capacity has on the flow of alternating current is not the same in every circuit. If in Fig. 21 for the inductance case the generator is turned at a uniform speed we can compute the apparent resistance of the circuit by Ohm's Law.

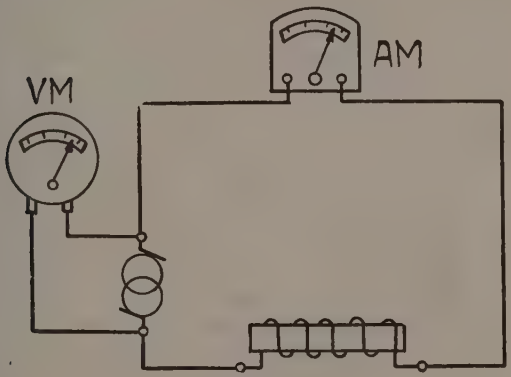


Fig. 21

The voltmeter reading divided by the ammeter reading will give us a value of apparent resistance that is greater than the number of ohms in the coil winding when measured on a Wheatstone bridge. Evidently the total number of ohms in the circuit is due partly to the resistance of the winding and partly to the effect the inductance has upon the current flow. If now the generator is turned more rapidly and again the voltmeter reading is divided by the ammeter reading, the number of ohms will be greater than in the first case. Since the resistance has not changed the effect must be due to

the inductance and we find that for any given inductance the more frequent the alternations of the generator the smaller will become the current indicating that the apparent resistance opposing its flow increases with the frequency.

We note from the preceding section that inductance in an electrical system is comparable to inertia in a mechanical system. The resistance which inductance offers to the flow of an alternating current is very similar to the resistance of inertia of the wheel which must be overcome by a mechanical force. The alternating voltage is analogous to the alternating force, the flow of current to the motion of the wheel and the apparent resistance offered by the inductance to the inertia of the wheel. There is a law covering the relation of frequency of an alternating current to the inductance opposing its flow which is as follows:

The effect due to inductance depends directly upon the frequency of the alternating current.

Returning to our theory of electromagnetic induction, the induced current depends upon the rapidity with which lines of force are cut and since an increase in frequency means that the alternations of current take place in a shorter space of time, the lines of force will be cut faster. This frequency of an alternating current is commonly expressed in the number of cycles per second. One cycle has been previously defined in Section II-A.

If in Fig. 21 the retardation coil is replaced by a condenser, as in Fig. 22, and the experiment repeated, it will be found that the number of ohms computed by dividing the voltmeter reading by the ammeter reading will be **decreased** when the speed

of the generator is increased. We thus find that the effect of capacity varies inversely with the frequency of the current.

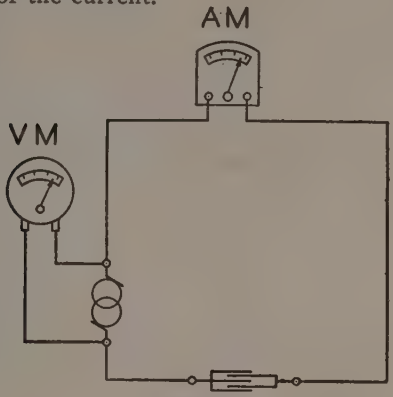


Fig. 22

Not only are inductance and capacity dissimilar circuit properties in this respect, but one will tend to neutralize the other. Let us repeat the experiment illustrated by Fig. 21 by inserting a condenser in series with the retardation coil as shown in Fig. 23. We find that by properly choosing our condenser the current flow is increased, thus proving that the inductance of the circuit has been at least partially neutralized. If we remove the inductance, leaving only the condenser in the circuit, we see that the current flow is less than with the combination.

Let us now try another experiment with the inductance again in series with the condenser. We shall find not only that capacity neutralizes the inductance to a degree, but if the speed of the generator can be adjusted to the proper value, the capacity will neutralize the inductance entirely.

Under these conditions, the only limit to the current flow is the pure resistance in the circuit, and when this is low, a very high current will flow. When the frequency is of such a value that neither

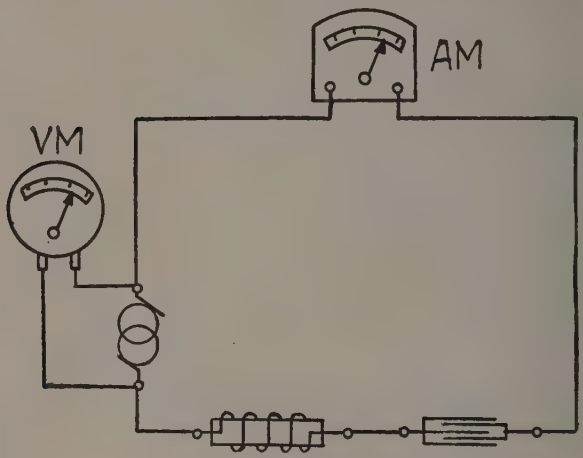


Fig. 23

the capacity nor the inductance effect predominates, the circuit is said to be **resonant**, and the frequency is called the **resonant** frequency of the circuit. At all higher frequencies the inductance effect predominates and at all lower frequencies, the capacity effect predominates. In this Section it has been pointed out that inductance acts very much as inertia, and capacity as elasticity, so if we have a device where these two properties exactly neutralize each other, we can illustrate the resonant principle. Let us study the spring-driven wheel shown in Figure 14, assuming that the spring is just strong enough to start the rim in motion as soon as a force is applied to the crank. If we

just start this system in motion, applying a force to the crank for an instant, the wheel will not stop upon the withdrawal of the force, but will oscillate a few times before coming to rest, as explained previously. If now we apply a force periodically, so timing it that just as the wheel stops rotating in one direction the force is applied tending to move it in the opposite direction, it can be seen that very large swings will result, even if the force applied is quite small. The condition in the resonant circuit is very similar, i. e., by applying a comparatively small electric force we set in motion large quantities of electricity.

The resonant principle is often employed in communication work, the tuning of radio and carrier current circuits being notable examples.

Reactance

It would be very convenient if we could express the effects of either inductance or capacity in ohms instead of henrys and microfarads, respectively. We have learned, however, that while the inductance may be fixed for any one coil, and the capacity may be fixed for any one condenser, their effects in a circuit when expressed in ohms will depend upon the frequency as well as the inductance or capacity values. These effects when expressed in ohms are called **reactance**, and the reactance in ohms due to inductance is calculated as follows:

Multiply the coil's inductance in henrys by 6.28 times the frequency of the alternating current in cycles per second.

As an example, the inductance of the 47-B retardation coil used in connection with the busy test

feature of an operator's telephone set circuit is .3 henry. We can find its reactance to a frequency of 1000 cycles per second as follows:

Reactance equals $6.28 \times 1000 \times .3$ or 1884 ohms.

To find the reactance in ohms of a condenser:

Multiply its capacity in microfarads by 6.28 times the frequency of the alternating current in cycles per second, and divide 1,000,000 by the product.

Let us suppose that we wish to find the reactance in ohms of the 2 mf. condenser in the subscriber's set to the flow of a current having a frequency of 1000.

Reactance equals $1{,}000{,}000 \div (6.28 \times 1000 \times 2)$ equals 79.6 ohms.

To find the reactance of a circuit having both capacity and inductance in series:

Find the reactance due to the condenser and the reactance due to the inductance, subtract the smaller from the greater.

To illustrate this let us find the net reactance of a 144 receiver in series with a 1 mf. condenser at 1000 cycles. The inductance of the receiver is about .033 henry.

Reactance of receiver equals $6.28 \times 1000 \times .033$ or 207 ohms.

Reactance of condenser equals $1{,}000{,}000 \div (6.28 \times 1000 \times 1)$ or 159 ohms.

Net reactance equals $207 - 159 = 48$ ohms and since the inductance predominates this 48 ohms is a net inductance effect.

Impedance

In direct current circuits we have seen that the resistance of any circuit by Ohm's Law is equal to the voltage applied across the circuit divided by the current flowing through it. The same relation holds true for alternating current circuits when the apparent resistance of the circuit is equal to the alternating voltage impressed across it divided by the alternating current flowing in the circuit. This apparent resistance usually contains some inductive or capacity reactance component and is not the same value we would obtain by measuring the resistance of the circuit with a Wheatstone bridge. For this reason and to distinguish it from direct current resistance we call the apparent resistance of a circuit to the flow of an alternating current its **impedance.** The impedance is usually designated by the letter **Z.**

Having learned how to express the effect of capacity or inductance in ohms, we now must consider how these ohms due to reactance combine with the ohms due to resistance. If, in Figure 21, we determine the reactance of the inductance coil in ohms, and add to it the ohms due to the resistance, we find that the total number of ohms is not the same as that we obtain by dividing the voltmeter reading by the ammeter reading. Further, if we replace the coil by a condenser, we again find that the sum of the ohms due to reactance and those due to resistance is not equal to the ohms obtained by dividing voltage by current. We conclude then that reactance and resistance combine in some manner other than simply adding, and are related in some way which is not very clear. It has

been determined that the proper way to combine resistance and reactance is as follows:

First, add all the inductive reactances together and all the capacity reactances together. Second, find the net reactance by subtracting the smaller from the greater. Third, find the total series resistance of the circuit. Fourth, to the square of this resistance add the square of the net reactance, and extract the square root of their sum. This gives the circuit's combined impedance.

As an example, let us find the impedance of a 38-A subset ringer to a 16-cycle current if the resistance is 1000 ohms and the inductance is 3.2 henrys. We know the resistance is 1000 ohms and the reactance is 6.28 $\times$ 16 $\times$ 3.2 or 321.5 ohms. The square of the resistance is 1000 $\times$ 1000 = 1,000,000. The square of the reactance is 321.5 $\times$ 321.5 or 103,362. The sum of these squares is 1,000,000 + 103,362 or 1,103,362. The square root of this is 1050 ohms, which is the impedance.

The symbol for impedance as stated above is **Z**, and can be used in connection with Ohm's Law in alternating current work to find current in the same way that **R** is used in connection with Ohm's Law in direct current work, thus I = E/Z.

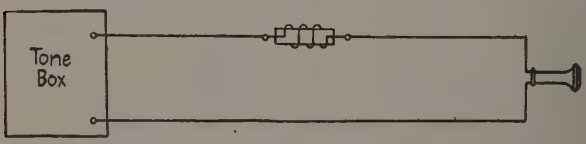


Fig. 24

As another illustration of the method used to combine resistances and reactances, let us refer to Figure 24 which shows a cable splicer's tone set

connected to a telephone receiver with a 47-B retardation coil in series. The resistance of this coil is 600 ohms and its inductance is .3 henrys. The reactance then is 6.28 × 800 × .3 = 1507 ohms, where 800 is the frequency. The receiver has a resistance of 1400 ohms and an inductive reactance of 1400 ohms at 800 cycles. The resistance of the two in series then is 600 + 1400 = 2000. The joint reactance is the sum of 1400 and 1507 or a total reactance of 2907 ohms. Following the rule stated above, we find the impedance to be the square root of 4,000,000 + 8,450,000, or 3520 ohms. Since the voltage supplied by the tone set is 9 volts, the current to the receiver is 9 ÷ 3520 = 0.0025 amps. or 2.5 milli-amperes.

Now let us connect in a condenser of 0.132 microfarads capacity as shown in Figure 25. We will not figure the actual current to the receiver, but we

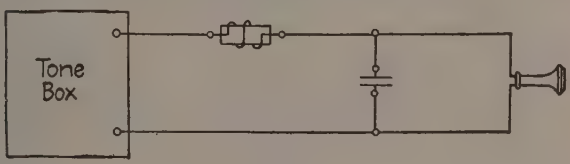


Fig. 25

will analyze conditions approximately to learn whether the current will be greater or less than the 2.5 milli-amperes obtained above. Neglecting for the time being the receiver, let us consider only the series circuit made up of the tone set, the retardation coil and the condenser. The resistance and reactance of the coil we already know to be 600 ohms and 1507 ohms respectively; the reactance of the condenser is 1,000,000 ÷ 6.28 × 800 × .132 or 1507 ohms of capacity effect. The combined reactance then is 1507 — 1507, or zero ohms, so the impedance

is the square root of 360,000 + 0 or 600 ohms. If the tone set were connected to such a circuit the current would be 9 ÷ 600 or .015 amperes = 15 milli-amperes. The voltage drop across the condenser alone would be IZ = .015 × 1507 or 22.6 volts, which is more than twice as great as the voltage impressed on the circuit. Now if we connect the receiver in shunt with the condenser, the inductance of the instrument will partially neutralize the effect of the capacity so that there will not be as much capacity reactance remaining to offset the inductance of the coil. It is not to be expected then that the total current in the circuit shown in Figure 25 will be as high as 15 milli-amperes, but it certainly will be much greater than the 2.5 milli-amperes obtained in the first case, because we are eliminating the effect of inductive reactance. Actually the current supplied the receiver will be about 4 milli-amperes, almost twice as much as under the first condition.

Now let us make connections as in Figure 26. It is seen at once that the tone set applies its full voltage on two parallel paths, the first consisting of the condenser and the second consisting of the re-

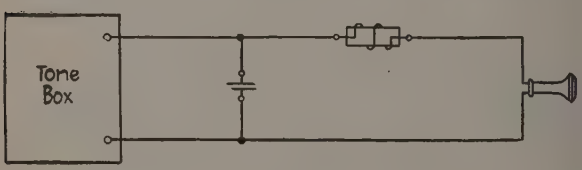


Fig. 26

ceiver and 47-B coil in series. In so far as the receiver is concerned then, the electric conditions are exactly the same as in the first case and the current supplied it will be 2.5 milli-amperes.

The arrangement of apparatus shown in Figure 25 is quite common in the telephone plant, and the reason for it is plain from the above discussion. Thus in the battery supply circuit of a cord circuit, the retardation coils in series with the battery oppose the flow of any alternating currents, and prevent the loss of alternating current energy through the battery. Again in other cord circuits condensers are connected in series with the tip and ring wires; these neutralize the effect of the inductive relays and permit the alternating currents to pass through the central office with but little loss.

ELEMENTARY PRINCIPLES— ALTERNATING CURRENTS

SECTION II-C

TRANSFORMERS

Transformer Action

A transformer is a device used in connection with alternating current, to which there is no corresponding device in direct current work. It consists essentially of two coils so associated that the magnetic field set up due to the flow of current through one, passes through the other. It is used to pass, so to speak, energy from one circuit to the other by means of the mutual induction between two windings that is by means of interlinkage of lines of force from one winding to another. With the exception of a special type known as an autotransformer, no metallic connections exist from one winding to the other. The transformer thus permits two circuits to be insulated from each other in so far as the transmission of direct current is concerned. It further permits the alternating current energy to be changed into a different form; for example, it may be in the form of high amperage and low voltage in the first circuit and in the form of high voltage and low amperage in the second circuit.

To understand the transformer's principle of action let us first refer to Figure 27, which shows an alternating current generator connected to the

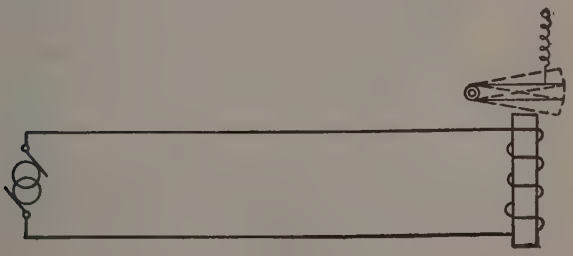


Fig. 27

winding of a simple form of relay designed to operate on direct current. The alternating current will cause the armature of the relay to vibrate back and forth very rapidly or to "flutter." The electrical energy in the winding of the relay is being transformed into mechanical energy, evidence of which is furnished by the fluttering of the relay armature. If, now, the lines of force which cause the vibration and which are being established first in one direction and then in the other were used to cut the turns of a second coil which might be substituted for the armature, as shown by Figure 28, a meter connected to this second winding would show that an alternating voltage was being generated in

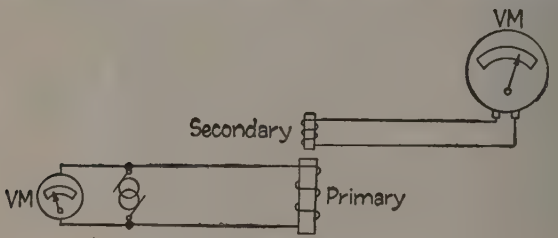


Fig. 28

it. The lines of force here are in motion and are cutting the conductors which are represented by the windings of the second coil. Lines of force in motion when cutting stationary conductors generate an E.M.F. in the same way that a conductor in motion when cutting stationary lines of force generates an E.M.F., as in the case of the magneto generator. In Figure 28 the winding connected to the generator would be called the "primary" of the transformer, and the winding connected to the voltmeter would be called the "secondary" of the transformer.

Transformer Ratio

The magnitude of the voltage generated by the lines of force depends first, upon the rapidity with which the lines of force expand or contract, and second, upon the number of series turns that are cut. It will be clear that, since the lines of force are due to current, the expansion or contraction of these lines depends upon the rate of change of the current which sets up the magnetic field. Figure 29 shows the primary and secondary of a transformer wound on an iron core. The closed iron core, since it reduces the reluctance of the magnetic

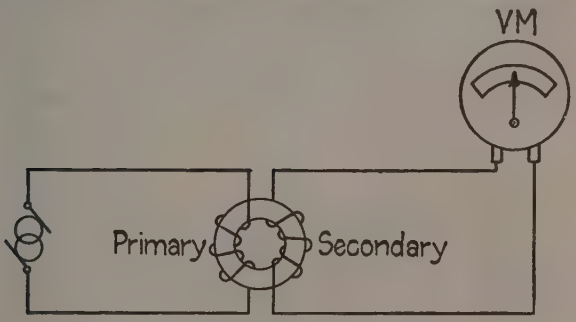


Fig. 29

circuit, increases the number of lines of force, and, therefore, makes the transformer more efficient. If the number of turns of the primary is the same as the number of turns of the secondary, the transformer is called a "one to one" and the voltage "generated" in the secondary will be approximately the same as the voltage impressed on the primary. If, however, the number of turns of the secondary is smaller than the number of turns of the primary, the transformer is called a "step-down" transformer,

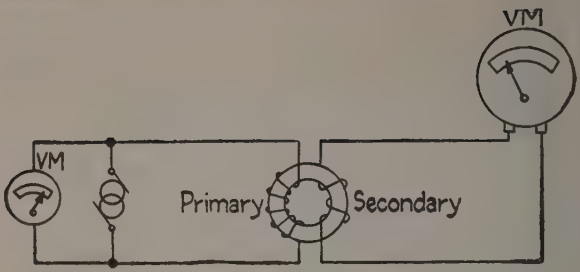


Fig. 30

and the voltage in the secondary is less than the voltage in the primary, as illustrated by Figure 30. If, on the other hand, the number of turns on the secondary is greater than the number of turns on the primary, the transformer is called a "step-

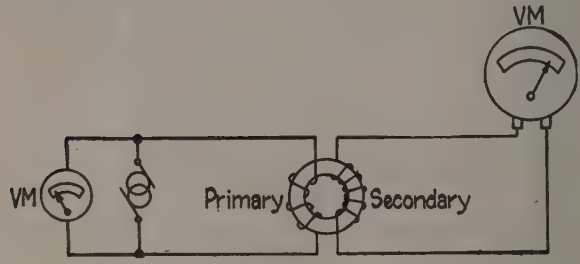


Fig. 31

up" transformer, and the voltage in the secondary circuit will be higher than that in the primary circuit as shown in Figure 31. In the telephone plant, "step-up" and "step-down" transformers are called "inequality ratio" coils.

Inequality Ratio Transformer

For transformers having only negligibly small energy losses in the core, there is a definite relation

between the voltage impressed on the primary, the voltage available on the secondary, and the number of turns in the two windings. The **voltages across the terminals of the transformer are directly proportional to the number of turns on the windings,** or as sometimes written in equation form:

$$\frac{V_p}{V_s} = \frac{N_p \text{ (turns on primary)}}{N_s \text{ (turns on secondary)}}$$

The ratio of primary turns to secondary turns is known as the "turn ratio." Thus, if the voltage impressed on the primary winding of a transformer is 10 volts (V_p) and the turn ratio ($\frac{N_p}{N_s}$) is 4 to 1, the voltage across the secondary can be determined.

$$\frac{V_p}{V_s} = \frac{4}{1}$$

$$\frac{10}{V_s} = \frac{4}{1}$$

So that V_s is one-fourth of 10 or 2.5 volts. Further, there is a relation between the **current** flowing in each winding and the number of turns on the windings. **The product of the current in the primary times the number of turns in the primary equals the product of the current in the secondary times the number of turns in the secondary.** This may also be stated by saying that the currents are inversely proportional to the number of turns, or writing it in equation form:

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Thus, if the current in the secondary is .018 ampere and the secondary has one-half as many turns as the primary, we can determine the current in the primary.

$$\frac{I_p}{I_s} = \frac{N_s}{N_p} = \frac{1}{2}$$

$$\frac{I_p}{0.018} = \frac{1}{2}$$

The primary current, I_p, is one-half of 0.018, or 0.009 ampere.

In dealing with circuits containing transformers, we frequently meet with an arrangement where we know the impressed voltage, the resistance of the load connected to the secondary and the turn ratio of the transformer, and we are asked to determine the effect that the load resistance has on the primary current. A little thought will establish that any energy we supply to a load connected across the secondary must be supplied from the only source of energy we have in our circuit, viz., the generator connected to the primary. It follows that the amount of current supplied by the generator will depend on the current flowing to the load. The ratio of the primary voltage divided by the primary current is consequently dependent on the electrical conditions in the circuit connected to the secondary. The ratio of volts to amperes, however, is **impedance,** so we conclude that the impedance of the primary depends on the impedance of the secondary. Actually the **primary impedance is approximately equal to the secondary impedance multiplied by the square of the turn ratio.** Thus if we impress 30 volts A-C. across a transformer

having a turn ratio of 1 to 4 and connect a 1200 ohm load across the secondary, the primary impedance can be determined by using the following equation:

$$Z_p = \frac{E_p}{I_p} = Z_s\left(\frac{N_p}{N_s}\right)^2$$

$$= 1200\left(\frac{1}{4}\right)^2 = 75 \text{ ohms}$$

From the above it can be seen that the "impedance" of one side of a transformer can be determined by the impedance of the load connected to it. If the secondary stands open, the primary also will act as if it were open; if the secondary is short-circuited, the primary will similarly act as a short-circuit on any generator connected to it. To speak of the impedance of a transformer, without mentioning the electrical conditions of the circuit in which it is placed, is meaningless.

One other feature of the transformer is worthy of consideration—its characteristic as a device for transferring energy. It has been mentioned above that the form of the energy supplied to the primary of an inequality ratio transformer may be different from that in the secondary since the values of E and I are changed and the power in both cases is the product of the two. The amount of energy that can be obtained from the secondary winding of a transformer is never greater than the amount supplied to the primary. Practically, there is usually less energy available at the secondary than is put into the primary because of the several energy losses which exist in any transformer. With careful design, these losses may be made very small, so that for ordinary work it is safe to assume that most

of the energy fed to the primary is available on the secondary side, or,

Primary Energy = Secondary Energy (approximately).

Autotransformers

There is one other type of transformer in which we are interested—the autotransformer. In this device, the primary and secondary windings are connected together metallically as well as magnetically, as shown in Figure 32. The primary and secondary windings are connected together and are both wound on the same iron core so that any lines of

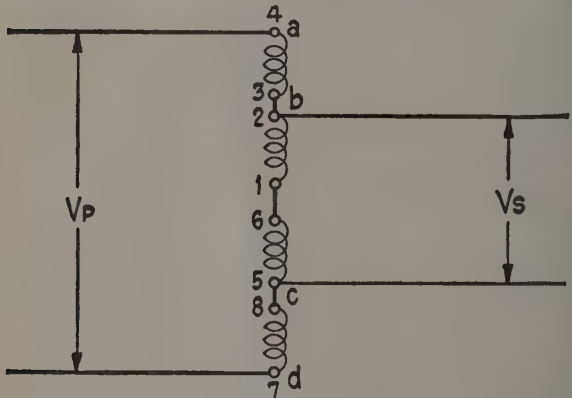


Fig. 32

force that thread one winding also thread the other. From the previous explanations it can be seen that the voltages on the primary and secondary sides are directly proportional to the number of turns in the windings, just as in the regular transformer. Thus, in the transformer shown in Figure 32 if there

are 150 turns between **b** and **c**, 750 turns between **a** and **d**, and 110 volts are connected across the primary **ad**, then the voltage across the secondary **bc** will be

$$110 \times \frac{150}{750} = 22 \text{ volts}$$

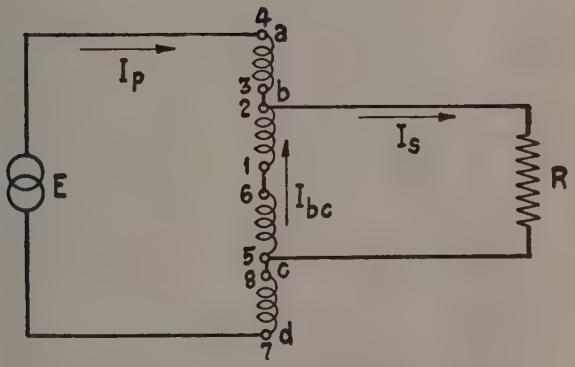


Fig. 33

In Figure 33 is pictured an autotransformer with voltage **E** connected to its primary and a load **R** connected to its secondary. Now, in a transformer of regular type, the whole of the primary circuit current and of the secondary circuit current flow through their respective individual windings. But in the autotransformer the primary and secondary currents flow in opposite directions through the winding common to both circuits, so that the net current through the common winding (winding **bc**

in Figure 33) is only the difference between the foregoing currents. Thus, in the autotransformer in Figure 33, just as in a regular type transformer

$$\frac{I_s \text{ (Current in secondary Ckt.)}}{I_p \text{ (Current in primary Ckt.)}} = \frac{N_{ad} \text{ (Total turns a to d)}}{N_{bc} \text{ (Common turns b to c)}}.$$

In the autotransformer, however,

$$\frac{I_{bc} \text{ (Current in Wdg. bc)}}{I_p \text{ (Current in primary Ckt.)}} = \frac{N_{ad} - N_{bc}}{N_{bc}},$$

which accords with the statement above that

$$I_{bc} = I_s - I_p.$$

It follows, therefore, that resistance losses in an autotransformer are lower than in a transformer of the usual type having the same size wire in its corresponding windings. Conversely, less copper is required in an autotransformer than in a regular transformer having the same load capacity and the same resistance losses, which is an economic advantage. The metallic connection between windings, on the other hand, is a disadvantage in power work, since it introduces the hazardous possibility of obtaining the full primary voltage on the load side of the device as, for example, if the primary circuit is operating under certain abnormal conditions.

Transformers in Telephone Circuits

In the telephone plant we meet with numerous circuits containing transformers of one type or another. Repeating coils are transformers, some of unity ratio, some of inequality ratio, the type chosen for any particular circuit depending upon the use to which it is put. Induction coils, such as are associated with the ordinary subscriber's set, are transformers; in telephone repeater circuits we find still other designs of transformers and on many telephone circuits we find autotransformers used to improve transmission. It can be seen, therefore, that transformers are of extreme importance in telephone work, and in addition to theory some knowledge of the plant practices governing their use is essential.

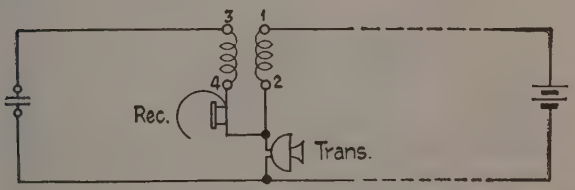


Fig. 34

In Figure 34 is shown schematically the circuit of an ordinary subscriber's set containing an induction coil. Here the fluctuations in current value in winding 1-2 induces an E.M.F. in winding 3-4 and this E.M.F. sets up a current which passes through the receiver.

In Figure 35 is shown an autotransformer as usually connected on circuits to improve transmission characteristics. Here the inequality of the turn ratio is used to raise the apparent impedance of a

section of line to make it equal to the impedance of the section on the other side of the transformer. The autotransformer is used because it permits the

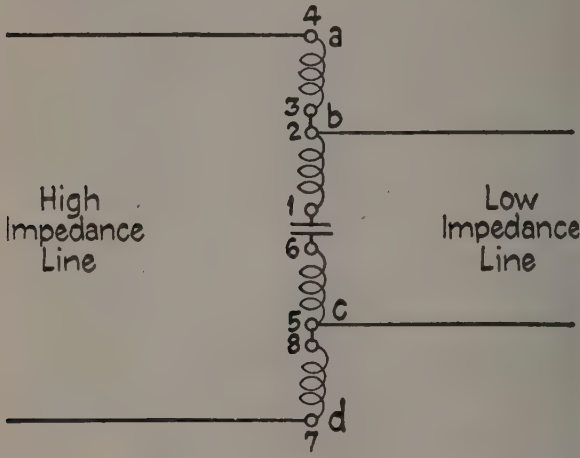


Fig. 35

wires of the adjacent sections to be connected metallically, and therefore permits them to be used for direct current signalling.

The repeating coil, which is one of the most common pieces of telephone apparatus, has the following construction and operating features. Each coil has four windings which are wound on a toroidal or doughnut-shaped iron core, and as usually employed, two of the four "unit" windings are connected in series to form a primary or "line" winding, and the remaining two in series form the secondary or "drop" winding. In telephone work it is essential that the two unit windings which make up the line winding have exactly similar electrical constants, and to this end they are wound on the

iron core side by side. Similarity between the unit windings used for the drop winding is not so important, so these, for economic reasons, are wound on the core separately. Figure 36 shows the position of the unit windings on the core, and gives an idea of the different methods of placing the wire on the core.

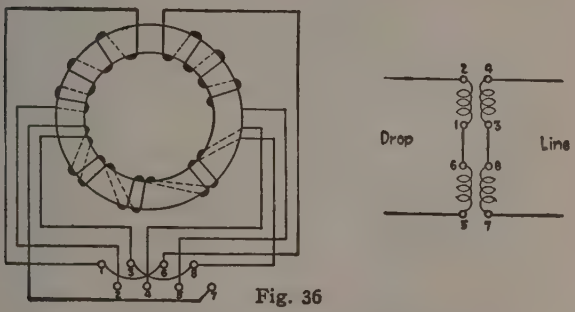


Fig. 36

On toll circuits, high-grade coils of special construction are used. In these coils, "stability" is an important consideration, that is, the construction must be such that the coil constants, particularly inductance, do not vary. It will be appreciated, from our discussion of magnetic substances, that if the iron core of a repeating coil becomes saturated, the change in the number of flux lines for a given change of current will become smaller. Also, that due to the residual effect, saturation of the core will influence its reaction to current flow. To prevent this saturation, such coils may have gaps cut in their cores, and these gaps filled with iron dust. By this construction the reluctance of the magnetic circuit is increased and the danger of saturation is minimized.

In addition to acting as a "phantom" or "simplex" coil, these transformers are frequently used to match lines of different impedances. In telephone circuits, it is highly desirable that all sections shall have the same impedance, and since it is frequently impracticable to build up a long circuit of sections having equal impedance, we frequently use coils to improve impedance conditions. For instance, if we wish to connect a line having a characteristic impedance of 1130 ohms to one having a characteristic impedance of 700 ohms we can improve transmission on such a circuit by establishing the connection through a transformer of such a turn ratio that, looked at through the coil, the 700 ohms looks like 1130 ohms. In other words, since the impedance varies directly as the square of the turn ratio, for this case we would choose a coil having a turn ratio determined as follows:

$$\frac{Z_p}{Z_s}=\frac{1130}{700}=\left(\frac{N_p}{N_s}\right)^2 \quad \frac{N_p}{N_s}=\sqrt{1.62}=1.27$$

or as near that ratio as possible.

ELEMENTARY PRINCIPLES— ALTERNATING CURRENTS

SECTION II-D

PRINCIPLE OF THE TELEPHONE

PART I

NATURE OF SOUND

Sound

During a telephone conversation the energy at the speaker's station is in the form of sound before it is transformed into electrical energy by the telephone transmitter. At the listener's station the energy is converted from electrical energy back into energy in the form of sound. Closely related in character to the electrical wave that carries the human voice from one telephone station to the other is that form of vibratory motion that we call "sound." The feeble electrical current must duplicate all those characteristics of the sound energy having to do with the intelligent understanding of the human voice. The telephone circuit must convert the sound energy into an electrical form and transmit it in such a way that it will have sufficient energy to operate the telephone receiver, giving the desired loudness. Yet the character of the so-called sound wave must not be greatly distorted. The voice quality, including even such subtle differences as exist between the voice of one person and that of another must be preserved.

We know sound is a form of vibratory motion in the air, but let us here digress to consider something more of its nature. If we stand on the shore of a still lake and cast a stone upon the surface of the water, the stone will set up a series of waves in the form of radiating rings moving away from the stone as a center, and at a more or less uniform velocity. If the stone is a small pebble, these concentric water waves are mere ripples, being much smaller than those that would be set up by a large stone, and at any single instant much greater in number for each foot of distance away from the center.

Fundamentally, that vibration of the atmosphere that creates a sensation in the human ear which we call sound is similar to the waves created by the stone striking the surface of the water. Sound, however, is wave motion of the air, and when in the form of speech is created by pulses of air under the control of the vocal cords and modified by the throat and mouth. The waves leaving the lips form radiating concentric spheres which like the water rings are ever expanding. We know that it takes an appreciable time for sound to travel, and under ordinary atmospheric conditions these waves move at a velocity of 1075 feet per second. We could actually calculate for ourselves this velocity by watching the flash from the muzzle of a gun at some distance away and measuring the time that intervenes before we hear the gun's report.

Sound waves vary greatly in their character. The voice of a bass singer has, for example, a fundamental frequency much lower than that of the voice of a soprano singer. In sound we refer to the frequency as "pitch;" a bass voice has a "low" pitch, and a soprano voice has a "high" pitch or we might say pitch is merely another expression for frequency, and the frequency of sound is the number of vibrations per second leaving the source.

The Human Voice

The human voice, even for a single vowel sound, is seldom of the nature of a simple sound or a pure tone consisting of the simplest wave or the sine wave. It is usually a mixed wave, consisting of that frequency, which we call the "fundamental pitch," with other smaller waves called "harmonics" superposed upon it tending to make it complex.

"Harmonics" have frequencies which are multiples of the fundamental.

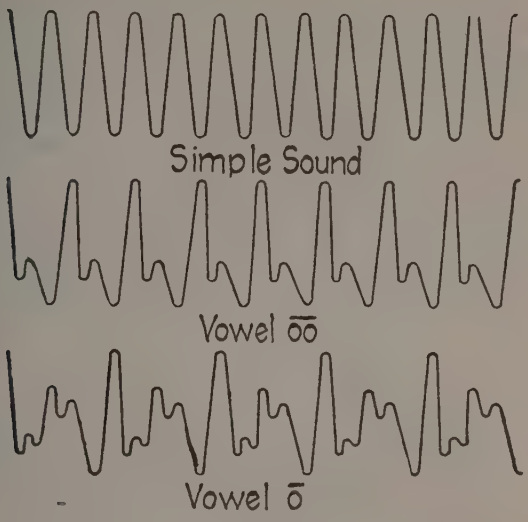


Fig. 37

Figure 37 illustrates the difference between the wave form of the simplest sound or a monotonous tone and two vowel sounds, that are perhaps most nearly like a simple sound yet consisting of a fundamental on which a series of harmonics is superposed.

The frequency range of the human voice, including both the frequency of the fundamental and the frequency of the harmonics, is a very wide range or band. In fact, were we to judge by sounds that might be heard by the most sensitive of human ears we could say that the frequencies range from 16 cycles per second to 30,000 cycles per second.

This extremely wide range, however, is not significant in the intelligent transmission of the human voice. Speech for the most part includes only those frequencies lying between 100 cycles and 5,000 cycles, and the transmission of the human voice gives commercial intelligibility when those frequencies between 200 cycles and 2,000 cycles are transmitted without appreciable distortion. In practice, we may test telephone circuits to determine their voice current transmission efficiency by using a single-frequency of 1,000 cycles. While this does not give accurate results for the entire band between 200 and 2,000 cycles in every case, it is sufficiently accurate for routine transmission tests on most telephone circuits.

Sound Resonance

If a singer sounds a clear, distinct note near a piano, it will be found that the string of the piano corresponding to the particular key will vibrate in unison, continuing even after the voice has been hushed. We explain this sympathetic vibration by saying the natural period of the string is in tune with the particular note. Any tightly stretched string, the prong of a tuning fork or a clamped diaphragm, has a natural period of vibration, and can be set in vibration most easily when the frequency of the sound corresponds to the period of vibration. Telephone transmitter and telephone receiver diaphragms have such periods, but are so designed that the period comes within the most important range of frequencies for the human voice. and the greater amplitude of vibration thereby accentuates these frequencies. On the other hand, however, there must be a natural distortion which

impairs the quality to a more or less degree. Resonance on the part of vibrating strings or diaphragms is analogous to resonant electrical circuits. In the electrical circuits the greatest current will be transmitted from a given alternating electromotive force if the inductance exactly neutralizes the capacity or if the circuit has zero reactance and is resonant to the particular frequency. Similarly, any amount of energy that may exist in a sound wave will cause the greatest sympathetic vibration when the natural period of the stretched string or diaphragm is resonant with the frequency of the sound.

The Simple Telephone Circuit

The relations between the problems of telephone transmission which we encounter, and the nature of sound discussed in the foregoing, may be briefly summarized as follows:

(a) A sufficient part of the sound energy reaching the transmitter diaphragm must be reproduced by the receiver diaphragm at the distant end to give sufficient loudness, or, as it is sometimes called, sufficient volume of transmission.

(b) The telephone instruments and connecting circuit must be so designed as to transmit without abnormal distortion the so-called telephone band of frequencies, or those lying between about 200 cycles per second and about 2,000 cycles per second, thus rendering the reproduced sounds intelligible.

(c) The transmission of sufficient volume and satisfactory quality must not be appreciably disturbed, or in more specific terms the

circuit must be reasonably free from crosstalk or noise coming from other circuits or other electrical sources.

The first telephone, as constructed by Bell, consisted of a telephone receiver only in crude form. It was used as a transmitter as well as a receiver, and the first telephone circuit was little more than that illustrated in Figure 38. The sound waves of

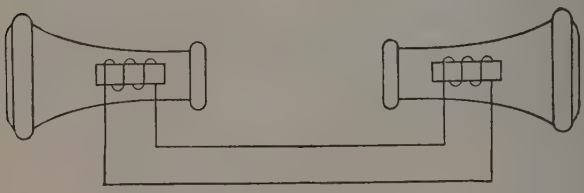


Fig. 38

the speaker's voice at one station established the sympathetic vibration of one receiver diaphragm. This, in turn, varied the width of the air-gap between one end of the bar magnet and the diaphragm, thus causing a change or kind of "quivering" of the magnetic field established by the permanent magnet through and around the telephone receiver winding. This generated a feeble alternating current in the winding having more or less the characteristics of the sound which impinged against the diaphragm. This feeble current was transmitted to the distant coil winding, and there established a feeble magnetic field of its own which, too, was changing, (or "quivering"), in sympathy with the magnetic field at the transmitting receiver. Here the action was reversed. This changing magnetic field was either weakening or strengthening the existing magnetic field of the permanent magnet, and consequently weakening or strengthening the magnetic

pull on the receiver diaphragm, thus causing it to vibrate, forming within itself a source of sound, and reproducing the spoken word at the transmitting station.

The Permanent Magnet of the Telephone Receiver

Though for many years the magnet of the telephone receiver was a bar magnet such as that illustrated by Figure 39, the receiver as we know

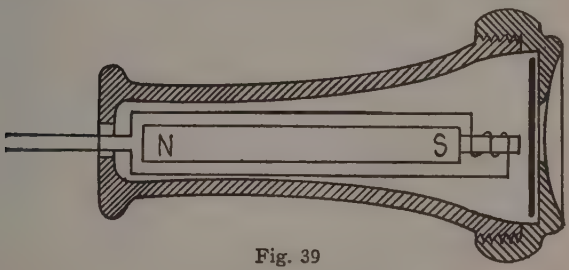


Fig. 39

it today has been greatly improved in its efficiency by the use of a horseshoe magnet, as illustrated by Figure 40.

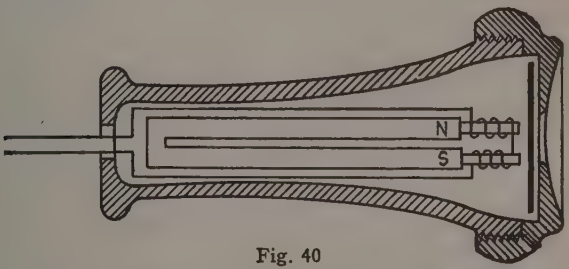


Fig. 40

Though it was necessary to use a permanent magnet at the transmitting station in the simple telephone circuit in order that there would exist lines

of force which could be set in motion and generate the feeble voice current, the permanent magnet could not be conveniently dispensed with even after the invention of the telephone transmitter. It might seem that the coil of the telephone receiver, when used as a receiver and not as a transmitter, would work equally as well with a soft iron core

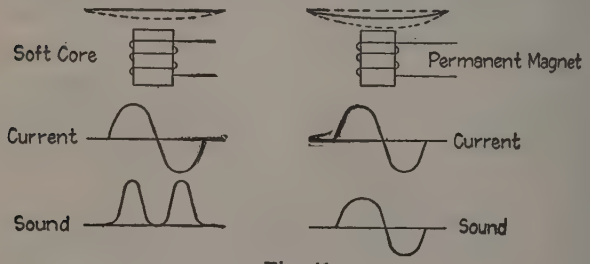


Fig. 41

as with a permanent magnet core, but this is not true. Let us refer to Figure 41, where the two conditions are compared. In the soft iron case for a complete cycle of current there is a magnetic attraction for the diaphragm creating a pull when the current is flowing through the winding in a positive direction and a similar magnetic pull for the other half of the cycle when the current is flowing through the winding in a negative direction. The diaphragm is thus attracted twice for one cycle, as illustrated by the dotted line, and two sound waves instead of one complete wave would emanate from the receiver diaphragm. Thus, the soft iron core would permit the telephone receiver to double the frequency of the transmitted speech. But on the other hand, and as it should be, the permanent magnet will not do this. At all times, regardless of whether the current is flowing through the winding or not, there

is a pull on the diaphragm and the heavy black line illustrates the displacement, greatly exaggerated, of the diaphragm on account of this pull. Now, if a cycle of alternating current flows through the winding, one-half of the cycle will merely weaken the pull and the other half will merely strengthen the pull, thereby permitting the diaphragm to make one vibration instead of two vibrations for the cycle. This will give a reproduction of sound of the same frequency as the current through the receiver winding. There is yet one other advantage of the permanent magnet in the receiver's operation. It so happens that the total amplitude of vibration will be much greater where the alternating current in the winding acts to weaken or strengthen the pull rather than to create a pull where none originally existed.

This principle brings out reasons for the careful use of telephone receivers whether they be substation types or operators' telephone set types. We have learned that permanent magnets could be demagnetized by jarring or rough treatment. They can also be demagnetized if direct currents flow through their windings in the wrong direction. Sometimes this happens to the receivers in the telephone plant, and in consequence transmission is greatly impaired. The Central Office man knows from experience that after using a head receiver as a test receiver, which use results in the 24-volt Central Office battery sooner or later demagnetizing the permanent magnet, the receiver should not be used on an operator's head set. Another practical illustration is the occasional circuit where the receiver is not in series with the condenser, and has a direct current through its winding as well as the voice current. In this case the receiver must be

poled, that is so connected that the current will strengthen rather than weaken the magnet.

The Telephone Transmitter

Though the telephone receiver's efficiency is greatly increased by the use of the strong horseshoe magnet, it is not efficient when used as a transmitter because the sound energy striking the diaphragm is very feeble and even though efficiently converted into electrical energy, does not give sufficient voice current for the average telephone circuit. In order that a separate energy supply might be introduced and the voice current thereby greatly increased, the carbon granule type of transmitter was invented.

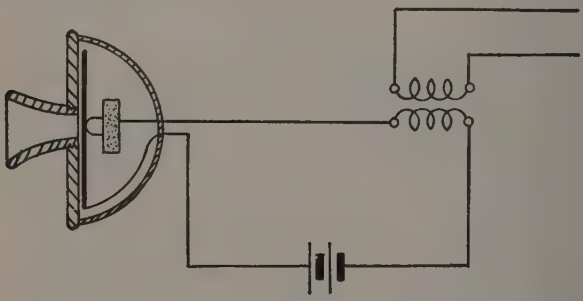


Fig. 42

Figure 42 illustrates the telephone transmitter. It works on the principle of the vibrating diaphragm, varying the resistance of a battery circuit through the primary winding of an induction coil instead of generating electrical energy by means of electromagnetic induction. The varying resistance of the carbon granules varies the value of the direct

current flowing from the battery through the primary of the induction coil. This varying current in the primary of the induction coil induces an alternating current in the secondary of the induction coil having similar characteristics to the sound which strikes the diaphragm through the transmitter mouthpiece.

ELEMENTARY PRINCIPLES—ALTERNATING CURRENTS

SECTION II-D

PRINCIPLE OF THE TELEPHONE

PART II

TRANSMISSION FEATURES OF THE SUBSCRIBER'S TELEPHONE CIRCUIT

Magneto Subset

Figure 43 represents the principles of the simplest telephone circuit using the telephone transmitter. Here we have essentially two local battery subscriber sets connected by a line having resistance. The magneto ringing generator, the ringer, and the switchhook are omitted for clearness, leaving only the essential transmission features. Here the variable resistance, consisting of carbon granules in the transmitter, has flowing through it a current from three dry cells, giving a voltage of approximately four and one-half volts in series with the primary of an induction coil. Sound impinging

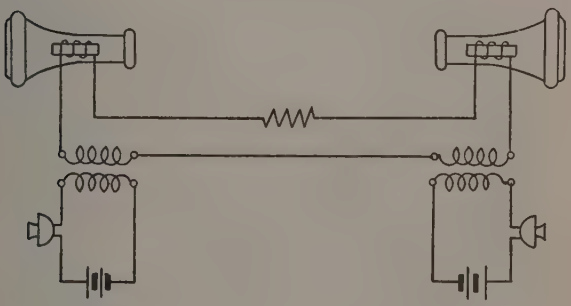


Fig. 43

upon the diaphragm of the transmitter varies its resistance, thereby fluctuating the current flow, and these fluctuations through transformer action induce an alternating current in the secondary of the induction coil which flows through the home receiver and the distant receiver in series. The alternating current flowing through the home receiver repeats the spoken word and we recognize this as "side tone." The same current, though somewhat

reduced, flows through the distant receiver, thereby accomplishing sound transmission.

The actual magneto line with all the circuit features of the magneto subscriber's set indicated is

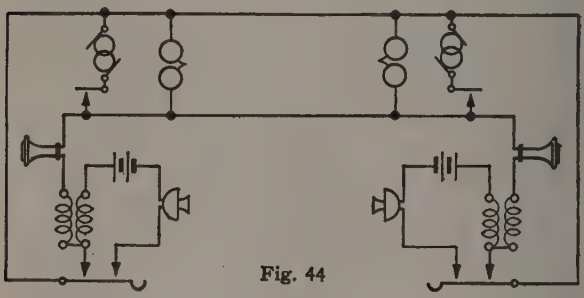


Fig. 44

shown by Figure 44. The generator is so arranged that a spring contact closes it across the circuit when the generator is turned, but leaves it open when not in use. This prevents a shunting of the voice current through the resistance of the magneto's armature. On the other hand, the bell must be bridged across the circuit at all times, and a similar arrangement would not be practicable for it. However, the bell is of such high impedance that the shunting effect is not so great as to appreciably affect transmission. The switchhook opens both the transmitter circuit and the receiver circuit when the receiver is on the hook, thereby conserving the energy of the dry cells when not required, and preventing the ringing current from flowing through the receiver or the receiver shunting the bell. In order to simplify the switchhook connections, there is one contact which is common to both the local transmitter circuit and the line or receiver circuit, but this common connection does not

affect the transmission features, and the local circuit and line circuit are as independent of each other in this respect as the arrangement shown by Figure 43.

If magneto sets are terminated at a magneto switchboard instead of in a direct private line, as is the case illustrated by Figure 44, there must, of course, be bridging drops associated with each jack in which the subscriber's line is terminated. But by means of a special contact on each jack these drops can be opened off the line when a connection is up, thereby preventing them from shunting the transmission. On the other hand, the cord circuit itself must have a bridged drop which will shunt the circuit during talking in order that the operator will receive the "clearing" signal or "ring off." Like the ringer, this drop is of high impedance.

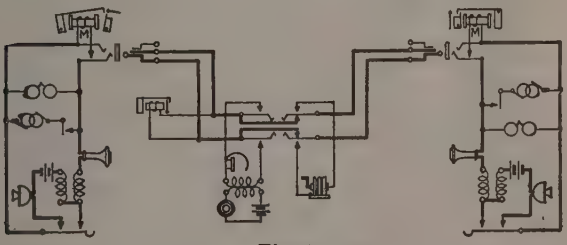


Fig. 45

Figure 45 illustrates two terminating magneto telephones and a connecting cord circuit. Here the winding **M** of the ringdown drop is open when the plug is inserted in the jack.

Other than the circuit operating features, voice transmission over a local battery telephone connection would depend upon the type of instruments used, the voltage of the local battery, and the length

and kind of line between the two stations. For this reason care must be exercised to insure that the specified instruments are used at the subscriber's station and that the battery voltage does not fall below the specified value. If the voltage of the dry cells at both stations should fall considerably below the normal voltage, we should find the distance over which satisfactory transmission could be obtained appreciably decreased. If the voltage at one station should fall appreciably below the normal value, the transmission from that station to the distant station would be impaired, but there would be no difference in the transmission in the other direction. The fundamental explanation of this is that every subscriber's station has a definite receiving efficiency and a definite transmitting efficiency which are in some respects independent of each other. The receiving efficiency depends upon the type of instruments, the line circuit and the proper subscriber's set connections, while the transmitting efficiency depends also in addition to these things upon the proper direct current being supplied to the transmitter. A weak direct current would mean that the vibration of the transmitter diaphragm would give fluctuations in current that would induce an insufficient value of alternating current into the line circuit.

The Common Battery Subset

If instead of the arrangement shown in Figure 43 we should connect a receiver and transmitter, as shown by Figure 46, we could use one battery instead of two to supply the transmitter current. In this figure we have shown the battery connected in series, which would give the same current

through both transmitters provided the line had excellent insulation, but we could accomplish the same result with a single battery bridge across the circuit in series with an inductance, as shown by

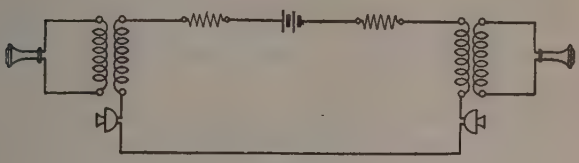


Fig. 46

Figure 47, if this battery was in the middle of the circuit. But in case the battery was not in the middle of the circuit or if one subscriber's line consisted of cable conductors of higher resistance than the other, the battery supply to the transmitters would not be the same. In both Figures 46 and 47 the

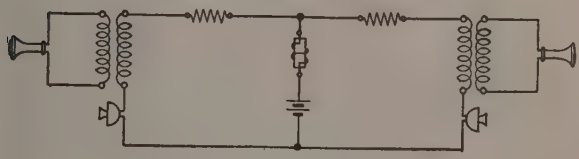


Fig. 47

voltage of the battery would have to be appreciably greater than the voltage of either battery shown in Figure 43 because the resistance of the line is in series with the transmitter.

Neither of the single battery arrangements, as shown in Figure 46 nor Figure 47 is actually used in practice inasmuch as either would give an unbalanced circuit condition which would make the circuit very susceptible to noises and crosstalk from

other circuits. A simple modification of Figure 47, with two equal retardation coils on either side of a single grounded battery, is used, however, in certain private branch exchanges where practically all telephones are in the same building or where the difference in the resistance of the subscriber's loop is negligible, and each telephone transmitter receives about the same current supply. Figure 48 shows in schematic form a station to station connection in such a private branch exchange. Two retardation coils are used instead of one, thereby

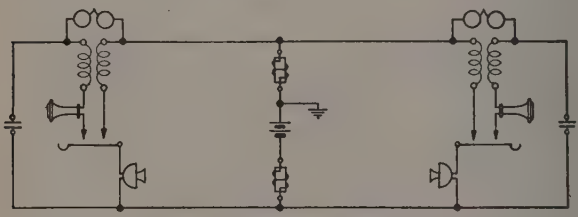


Fig. 48

balancing the line circuit. The standard subset is shown here which includes additional circuit features for proper common battery operation and is so designed as to give the best transmission efficiency. The switchhook connection provides a means for common battery supervision and the ringer is in series with a condenser when the receiver is off the hook, giving a closed circuit to the 16-cycle alternating current used for ringing but an open circuit to the direct current from the common battery which is used for signaling the operator. When the receiver is off the hook, the condenser is in series with the receiver circuit, thereby neutralizing in part the inductance of the receiver windings.

While somewhat similar in appearance, the common battery subscribers' station is fundamentally different in its operating principles from the local battery set. In the local battery set the induction coil acts merely as a transformer, converting the fluctuations of direct current in the local transmitter circuit into an alternating current, which the secondary winding of the induction coil impresses on the line terminals. In the common battery set, however, the induction coil acts as an autotransformer and is so designed that the impedance of the subscriber's set when measured at the transmitter terminals with the set connected to an average subscriber's loop is approximately equal to the resistance of the transmitter itself. This autotransformer action steps up the fluctuating voltage across the transmitter caused by the varying voltage drop which of course at any instant is equal to the resistance of the transmitter multiplied by the current flowing through it. This increased voltage across the terminals of the subscriber's set results as we shall see in the section on "Attenuation" in lower losses in the circuit from the subscriber's set to the central office.

In Figure 48 we find that the bridged battery does not appreciably shunt the transmission from station to station because the retardation coils have very high impedance to the high frequency voice currents but a comparatively small resistance to the direct current which supplies the transmitter. If we should replace the retardation coils with non-inductive resistances, we would find that while the supply of direct current to the transmitters would not be impaired, the transmission from station to station would be greatly reduced.

In Figure 48 we have seen how the talking bat-

tery through retardation coil connections is bridged across the cord circuit at the private branch exchange, thereby making the single battery supply both subscribers' stations. The same battery is also used for all cord circuits. This effects further economy not only by using one battery for two subscribers' stations, but also by using one battery for all subscribers' stations, and this is possible because the battery circuit has such low resistance that it does not permit the very faint voice current from any one connection which might flow through the retardation coils of the battery to give sufficient alternating voltage drop across the terminals of the battery to create crosstalk in the other circuits.

In order that the use of a common battery may be applied not only to the cord circuit of a private branch exchange where the stations are all in the same building but to a Central Office having subscribers' loops which vary from zero to several miles

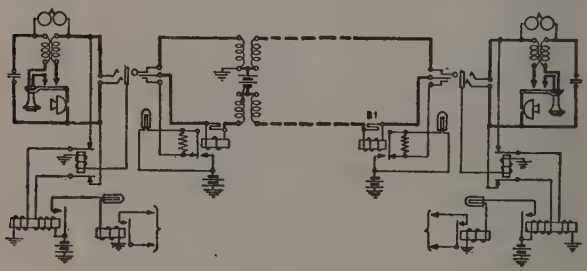


Fig. 49

of cable in length, thereby giving a wide variation in the resistance through which the battery must supply the transmitter current, two modifications of Figure 48 give more nearly a constant current to the transmitter by preventing, for example, a zero

loop station almost entirely shunting the current that would flow through a very long loop station, as would be the case in Figure 48. The more common of the standard Central Office common battery arrangements is to use a repeating coil with four windings and connected as shown in Figure 49. Here the transmitter current will, of course, depend directly upon the voltage of the battery, divided by

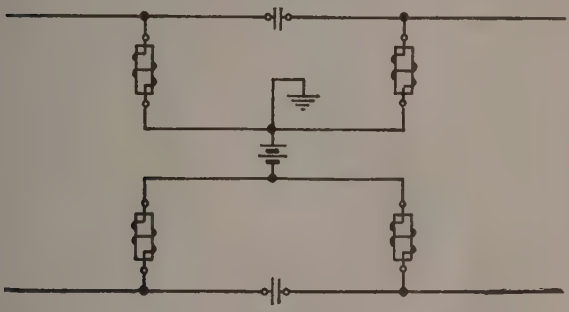


Fig. 50

the resistance of the repeating coil in series with the resistance of the station and in series with the resistance of the loop. It will be independent of any shunting effect the other station might have. This is the standard station to station connection for manual subscribers' offices, and the same figure shows all of the circuit's operating features. Figure 50 accomplishes the same result as Figure 49 by the use of retardation coils to supply current in each direction instead of through a direct bridge, as shown in Figure 48. Here the voice current has a path through a 2 mf. condenser, which separates the two stations in so far as direct current flow from the battery is concerned. This arrangement

is standard in many machine switching installations.

It may be well to digress here for a few moments and study the transmission losses that are encountered in an ordinary common battery subscriber's loop. As can readily be seen from an inspection of Figure 49, the current flowing through the transmitter of a common battery subscriber's station is equal to the central office battery voltage divided by the sum of the series resistances of the entire circuit. As the length of the loop increases and consequently its resistance, the current flowing through the transmitter naturally becomes smaller. As the standard transmitters used in the plant are more efficient at larger currents, it can readily be seen that a reduction in current would cause a reduction in efficiency. This loss is commonly called the current supply loss and applies only to the transmitting efficiency of the subscriber's set, that is, the loss exists only when the subscriber is talking.

In addition to the current supply loss, we have another loss due to the reduction of the alternating current as it flows from the subscriber's station to the central office. This reduction, of course, is equal in the two directions, that is, it will be the same amount either if the subscriber is talking to the central office or someone in the central office is talking to the subscriber. This loss is commonly called the receiving loss of a subscriber's station and when added to the current supply loss, the sum of the two equals the transmitting loss of the subscriber's loop.

From the above it can readily be seen that there is a considerable difference in the transmitting efficiency of a subscriber's line having a long loop and

one having a short loop. In practice there are two common ways of compensating for this:

(a) Using the more efficient transmitters on the high resistance subscribers' loops.

(b) By the use of larger cable conductors for outlying stations. This, of course, decreases the series resistance, thereby increasing the current through the transmitter, for example:— a No. 22 gauge cable pair has a resistance of approximately 171 ohms per mile while a No. 24 gauge cable pair has a resistance of 270 ohms per mile. In addition to improving the transmission by increasing the current supply, the larger gauge has a lower transmission equivalent, or in other words gives less transmission loss per mile than the smaller gauge cable. (In practice, where No. 19 gauge conductors are not available, two No. 22 gauge cable pairs are sometimes connected in parallel to give the same battery supply. While the same transmission improvement due to the reduction in current supply loss is effected, as if No. 19 gauge conductors were used the same overall improvement in the transmitting efficiency is not effected since two cable pairs in multiple are no better than a single cable pair for receiving efficiency.)

Miscellaneous Transmission Features in Local Telephone Connections

There are important transmission considerations in all local telephone work. A subscriber's station may give satisfactory transmission in so far as a call from one subscriber to another is concerned, but may not give satisfactory transmission

over a very long toll circuit, and although the station might be used only occasionally for such toll service it should be appreciated that when so used very expensive facilities are rendered inoperative due to the improper functioning of the single equipment unit. If conversation is not possible there is a loss to the Company because it has incurred the same or in many cases even greater expense in attempting to give the service than it would have incurred had the subscriber been able to talk. Further, there is disappointment on the part of the

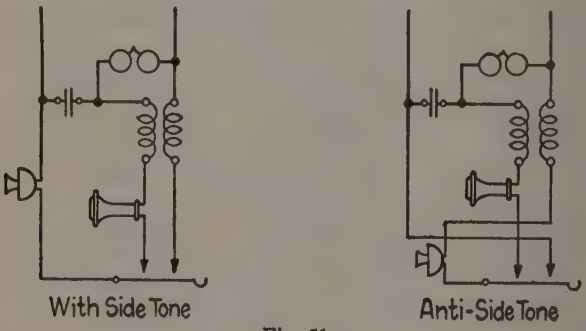


Fig. 51

subscriber and an inclination to refrain from the use of long distance service in the future. It is, therefore, imperative that we consider plant not only from the standpoint of merely talking from one subscriber to another in the same exchange area, but we must also take into consideration many things that may not seriously affect the local transmission, but do seriously affect long distance transmission. To illustrate, Figure 51 shows a connection that can be made in any local telephone circuit which will tend to eliminate the loud side tone which is disagreeable to many subscribers, but this

change seriously impairs the transmission efficiency of the subscriber's telephone circuit. Another illustration is the B-1 supervisory relay in the local cord circuit which has a non-inductive winding designed to shunt the inductive winding, thereby eliminating the otherwise high impedance path to high frequency voice current. It is a known fact that the operation of the B-1 relay would actually be improved in so far as its supervisory function is concerned were the non-inductive winding removed, but transmission would be impaired.

In cable layouts it was once the practice to have multiple taps of extreme lengths on various cable pairs, thereby making the same pair accessible for additional telephones in various parts of the vicinity served by a particular cable. While these cable pairs may be economical from the standpoint of ready facilities for new stations and flexibility in making cable pair changes, each branch or section of cable impairs transmission due to the bridging of capacity, which gives a shunting path for the telephone conversation.

The foregoing cases are only a few representative ones, but illustrate how comparatively common practices have seriously impaired transmission in the past. There are many others, but these can not be enumerated here. Perhaps the only guiding rule is to understand the electrical principles upon which the transmission of the human voice are based, and to perform our work accordingly.

ELEMENTARY PRINCIPLES—
ALTERNATING CURRENTS

SECTION II-E

ATTENUATION

Attenuation

In the preceding section it has been shown how the energy of the sound waves produced by the voice moves the transmitter diaphragm of the telephone, thereby translating the mechanical energy into electrical energy. The telephone system is designed to transmit as much of this energy as possible from one telephone to another, no matter whether the instruments connected are located in the same city or at opposite ends of the country. When the sound received at the receiving station is much lower in volume than the original spoken words, it is evident that some of the energy must have been lost in transmitting it from one point to the other. This loss of energy is commonly called transmission loss, and is made up of all the losses in the individual parts of the circuit. With a few exceptions, such as amplifiers, each piece of apparatus introduced into the talking circuit causes some transmission loss and, in addition, there is the loss in the line itself, which increases with the length. This loss in the line is known as the attenuation loss or attenuation of the line.

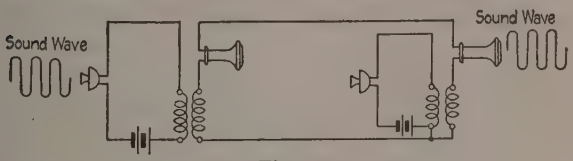


Fig. 52

If one telephone set is connected directly to another as shown in Fig. 52, the sound received will be slightly louder than the original words spoken into the transmitter since the transmitter itself is an amplifying device. The alternating current pro-

duced by the transmitting set flows directly to the receiving set, with nothing between to impede it or shunt out any part of it. If, however, a length of cable, say, 20 miles of 19 gauge, is placed between the two instruments, the sound reproduced by the receiver will be much lower than that picked up by the transmitter at the originating end. This is illustrated in Fig. 53, where the difference in

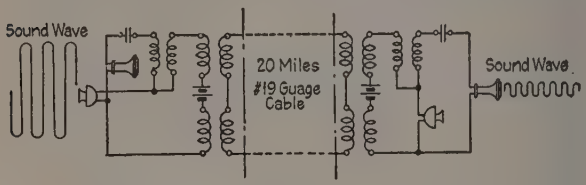


Fig. 53

height of the sound waves indicates that a considerable portion of the energy has been lost in traveling from the transmitter to the receiver. Practically all of this loss is due to the attenuation of the cable itself.

Let us see what becomes of this energy that has been lost in the line. We know that a cable circuit offers resistance to the flow of current and we also know that there is capacity or a condenser effect between the two wires of the circuits. In addition, all circuits have a certain escape of current or leakage between wires, these leaks becoming larger as the insulation becomes poorer. The current which flows through these leaks is lost. This loss or leakage is ordinarily very low on cable circuits, but on open wire circuits, especially in rainy weather, it may be quite high.

We know now that a telephone circuit has at least three characteristics, namely, resistance, capacity and leakage. These are illustrated in Fig. 54. We also know that the current which transfers

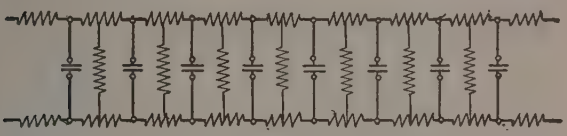


Fig. 54

the electrical energy from one end of the circuit to the other is an alternating current, and it is necessary in explaining the action that takes place to assume something of like character. Let us assume that the two wires of the circuit are replaced by two water pipes connected at the originating end to a pump which applies pressure first to one pipe and then to the other. At both the originating and receiving ends we will place a meter which will indicate at all times the number of units of energy. At the originating end this meter will indicate the number of units of energy transmitted to the system and at the receiving end the number of units delivered by the system. At intervals throughout the length of the two parallel pipes, short lengths of pipe will be connected from one side of the line to the other, each of these short lengths having an elastic watertight diaphragm across the center of it. In addition, a series of very small paths will be introduced between the two main pipes. These paths represent the leakage paths of the system. This device is shown in Fig. 55. The friction which the pipe offers to the flow of water corresponds to the resistance of a telephone circuit to the flow of an electric current, the pipes with the elastic dia-

phragms correspond to the condenser effect of a telephone circuit, and the small holes or leaks correspond to the leakage.

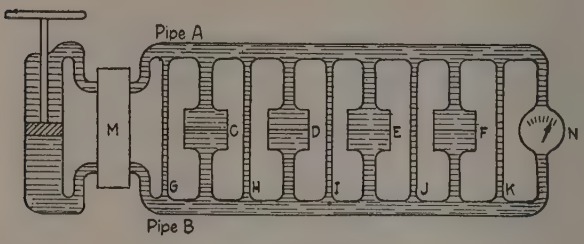


Fig. 55

Referring to Fig. 55, if we now apply pressure to pipe **B** by means of the piston of the pump, water will tend to flow through the pipe toward the far end. Some of this water, however, will flow up into the pipes **C, D, E** and **F,** stretching the elastic diaphragms to the point where the reactance offered by these diaphragms is equal to the pressure in the pipe at that point. A very small amount of the water will flow through the leaks **G, H, I,** etc., and the remainder that overcomes the resistance of the pipe will flow through the meter **N.** If we now reverse the piston of the pump and apply pressure to pipe **A,** the direction of the flow of the water will be reversed. As the pressure is taken off **C, D, E** and **F** from the **B** side, the water they have been holding flows back into pipe **B** and returns toward the pump due to the suction of the piston. Shortly after the pressure from pipe **A** forces water into the compartments on the opposite side of the diaphragms, some water is again lost by flowing through the leakage paths and the remainder overcoming the friction of the pipe again flows through

the meter **N**, but this time in the opposite direction. If readings are taken at the same time on meters **M** and **N**, it will be found that the number of units of energy registered on meter **N** is considerably less than the number of units delivered to the system at **M**. In other words, a considerable portion of the energy produced by the pump has been lost or attenuated in transmission from **M** to **N**.

A telephone circuit has the same characteristics as the pipe system explained above, and when an alternating voltage is impressed across the originating end approximately the same action takes place. An electric current, however, flows instead of the water in the pipe system and the energy de-

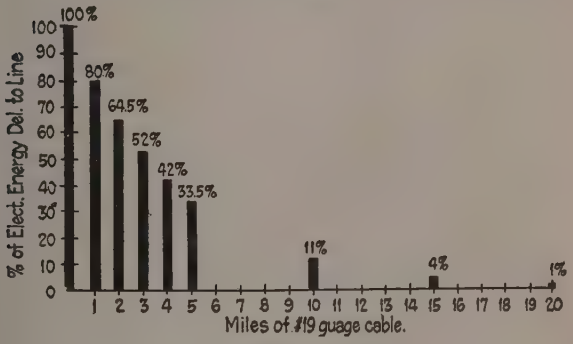


Fig. 56

livered to the far end is electrical energy. Fig. 56 illustrates the manner in which the electrical energy is attenuated as it is transmitted along a circuit consisting of 20 miles of 19-gauge cable inserted in the center of a long cable circuit. It will be noted that of the total amount of electrical energy delivered to the 20 miles of cable 20 per cent. has been lost in the first mile, an additional 15½ per cent. in

the second mile and so on until at the end of the 20th mile we have remaining only 1 per cent. of the total energy that was delivered to the circuit at the originating end. This figure represents graphically the loss in electrical energy which is known as the attenuation of a telephone circuit. Another interesting feature of the curve which should be noted is that the attenuation does not increase directly with the length but follows a curve drawn through the top points of the heavy vertical lines. This curve drops off sharply for the first few miles of the circuit and continues the same percentage drop for each mile of cable. That is the energy leaving any one mile section of the cable is always a definite percentage of the energy entering the other end of that same one mile section. For example, at the end of the first mile we have remaining 80% of the total energy, at the end of the second mile 64.5%, at the end of the third mile 52%, etc. Now the 80% at the end of the first mile is 80% of the total energy entering the circuit, the 64.5% at the end of the second mile is approximately 80% of 80% or 80% of the energy entering the second mile, and the 52% is 80% of the energy entering the third mile or 80% of 64.5%. In other words, for every unit of length of a uniform circuit the attenuation is equal to a definite percentage of the amount of energy entering that particular unit of length. This percentage factor varies with the different types of facilities.

If we now increase the size of the condensers or increase the leaks in the system, the attenuation will increase since more electrical energy will be lost due to the increase in capacity and leakage. It is desirable, therefore, to keep capacity and leakage of telephone circuits as low as possible,

and for this reason we remove trees from open wire leads and boil out cable splices to decrease the leakage. In cable circuits dry paper is used for insulation since this results in a lower capacity and leakage than can be obtained with any other practical form of insulation.

It was early realized that some method of determining the transmission loss of a telephone circuit would be necessary if satisfactory service was to be given. In order to measure anything it is first necessary to have a standard unit of measurement. With this idea in mind the telephone people years ago selected one mile of the type of 19-gauge cable first manufactured as the standard unit of measurement. This cable had a capacity of .054 m.f. and a resistance of 88 ohms per circuit mile. One mile of a cable of this type was known as a mile of standard cable.

In order to determine the transmission loss of any circuit two observers would talk over the circuit and then over a variable length of standard cable. When the standard cable was varied until the same volume of sound was obtained over it as over the circuit to be measured the number of miles of standard cable was taken as the loss or transmission equivalent of the circuit. For example, if 18 miles of standard cable gave the same transmission as the tested circuit, that circuit was said to have a transmission equivalent of 18 miles.

We have seen above that the energy leaving any one mile section of a long circuit is a definite proportion of the energy entering that same mile section. This is true of sections of standard cable but this unit of measurement has the big disadvantage that the ratio of the energy leaving a mile sec-

tion to the energy entering a mile section is not the same at all frequencies. This ratio decreases as the frequency increases. If we stop to think a minute we can easily see why that is so. A standard cable has a certain capacity, .054 m.f. per circuit mile, which is the same as if a small condenser of that value were bridged across the middle point of the mile of cable. We know that the reactance of a condenser to an alternating current decreases as the frequency increases. If the reactance decreases more current will flow through this condenser and consequently it will have a greater shunting effect as the frequency increases. Naturally less current will reach the far end of any particular one mile section and consequently the energy leaving the mile section divided by the energy entering that same section will give us a result which becomes smaller and smaller as the frequency increases.

To overcome this undesirable feature a new standard unit has been adopted for the purpose of measuring a transmission loss. This new unit is **"distortionless,"** that is, the energy leaving any unit divided by the energy entering that same unit will be the same at all frequencies. All telephone circuits are now compared from a transmission standpoint to this new unit. This is so adjusted that the ratio of power leaving a unit to the ratio of power entering a unit is .80 or in other words the energy is diminished to 80% of its original value as it travels through one transmission unit. Through two units it would be diminished to 80% of 80% or approximately 64% of its initial value.

The new transmission unit is not very much different in its effect on energy from the old mile of standard cable. In fact, it gives exactly the same

loss at all frequencies as we would obtain in a mile of the old standard cable at a frequency of 890 cycles per second. There is, therefore, very little difference between expressing an attenuation loss either as miles of standard cable or as transmission units. Due to its advantages, however, the transmission unit has now come into general use in the Bell System and is known as the "decibel," abbreviated db.

When the attenuation of a circuit becomes too great for satisfactory transmission due to the type or length of the facilities employed, the volume of sound at the receiving end becomes so small that it is difficult to carry on a satisfactory conversation. Such a condition is known as "poor transmission" and quite frequently results in complaints from the telephone subscribers. This is a condition which we, of course, wish to avoid and the telephone system is so designed that when everything is working properly there should be no cases of poor transmission. In designing the telephone system, if it is found that the attenuation over available facilities will be too great, this attenuation may be reduced in several ways, the most common of which are loading and the use of amplifiers. These will be explained in the following sections.

ELEMENTARY PRINCIPLES—ALTERNATING CURRENTS

SECTION II-F

LOADING

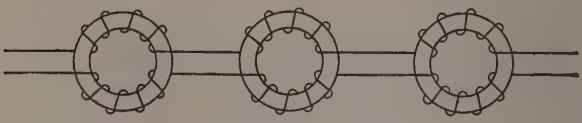
Loading

The purpose of a telephone system is to enable any two subscribers, no matter where situated, to be connected with each other within a reasonable length of time and to carry on without interruption a satisfactory conversation. If the distance between these two subscribers is very great, the attenuation of an ordinary telephone circuit consisting of a pair of wires would ordinarily be so large that the conversation would not be satisfactory. How can we reduce this attenuation? One method of accomplishing this is by means of "loading," since a loaded circuit will transmit more of the electrical energy than a non-loaded circuit. The question naturally arises: What is loading and how does it act to reduce the attenuation?

In reply to the first part of this question, we may say that loading consists of adding inductance in certain ways in series with the telephone circuit. This may be done in several ways, but the most practical form has been found to be copper wire having a very low resistance wound upon a closed iron core. These coils are spaced at regular intervals along the telephone line and are in series with it. Inductance could also be added by wrapping each of the copper conductors making up the telephone circuit with a spiral of iron wire and this method is sometimes used in submarine cables where it is impracticable due to mechanical difficulties to add the inductance in lumps, as it is added when coils are used. The spiral wire method, however, is less satisfactory than the lump method since in most cases it is not practicable. These two methods are illustrated in Figs. 57 and 58.

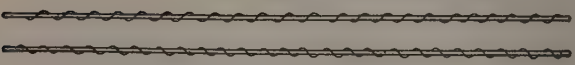
As stated in the foregoing, the most practical

method of adding inductance in series with the line has been found to be in the form of coils of copper wire having a very low resistance wound upon a



Loading Coils Connected in Line.

Fig. 57



Line Wires wound with spirals of Iron Wire

Fig. 58

circular iron core. In order to keep the two sides of the telephone circuit balanced this copper winding is divided into two equal parts, half of it being placed in series with one line wire and the other half in series with the second line wire. Since at any given instant the current is flowing in opposite directions in the two line wires that make up the telephone circuit it is necessary to have one-half of this coil wound on the iron core in the opposite direction from the other half. As may be seen from Fig. 57 this is the same as if the windings were wound all in the same direction as we go around the circular core. For example, take the first coil in Fig. 57. If viewed from the left it will be seen that the two halves are wound on the core in opposite directions but if we short the line wires between the first and second coils and follow the turns around the coil it will be noticed that the turns are all in the same direction as we go around

the coil. We have learned in the section on Electro Magnetism, that the direction of the magnetic field in an iron core depends upon the direction of flow of current in the windings. In order to have the electric currents flowing through the loading coil set up magnetic fields which will aid each other it is therefore necessary that the two halves of the coil be wound in opposite directions as explained above. If in cutting a loading coil into the circuit one of these windings is reversed it can readily be seen that the magnetic effect of the coil will be almost entirely neutralized and consequently it will not perform the work for which it was designed.

The circular iron core mentioned above is of a certain type of iron that will not normally remain magnetized after the current has ceased flowing. This factor is also quite important since, if the coil becomes permanently magnetized its inductance will be reduced and again it will not perform the work for which it is designed.

And now we arrive at the second part of the question, that is: How does loading reduce attenuation? Briefly stated, loading enables us to obtain the advantages of a high potential transmission system, that is, of transmitting the electrical energy from the sending end to the receiving end of the line with a high voltage and small current as compared with the smaller voltage and higher current which is found on non-loaded lines. This is the same step which has been taken by electric light and power people to reduce the energy losses in their transmission lines. We know that transmission lines carrying power are usually at a very high voltage, even though this power when delivered to our houses for lighting or other purposes is at a com-

paratively low voltage. The power is transmitted as indicated above at a high voltage and a low current due to the fact that this results in less loss of electrical energy in the line itself. The power people obtain this result by placing across the sending end of the line an extremely high voltage from a transformer or other device and by having at the distant end of the line a transformer, which reduces the voltage to commercial values. Since the power line is usually of very low resistance and low capacity as compared to a telephone circuit, these high reactances at the opposite ends of the line act almost as if they were placed within a short distance of each other and consequently the line in between introduces very little loss.

Telephone circuits, however, have very different characteristics from power circuits and also the frequencies at which we transmit electrical energy are ordinarily many times higher than those used by the power people. Our circuits have considerably more resistance and capacity and are often much longer than power circuits. We must, therefore, look for some additional means of reducing the current and raising the voltage of our circuits. The current is reduced by distributing inductance throughout the length of the circuit. Usually the voltage applied to the line is raised by means of the use of proper transformers and we now have the result that we desired to obtain, namely, a high voltage, low current system which gives us considerably lower losses of electrical energy than the low voltage, higher current system we previously had.

The effect of loading on a telephone line may be illustrated by a piece of string fastened at one end,

with the other end free. If we vibrate the free end rapidly up and down, and if the string is of sufficient length the waves set up by this motion will not travel the entire distance to the other end, but will rapidly become smaller as they travel along the string and finally die out entirely as shown by Fig. 59. But now let us place at frequent, uniform in-

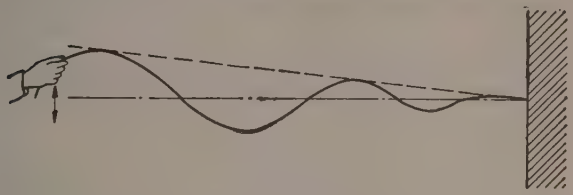


Fig. 59

tervals along this string small leaden shot and again vibrate the free end. It will now be found that the waves set up by these vibrations will travel the entire length and will reach the far end almost as large as when they left the originating end as shown by Fig. 60. If we increase the size of these shot, or

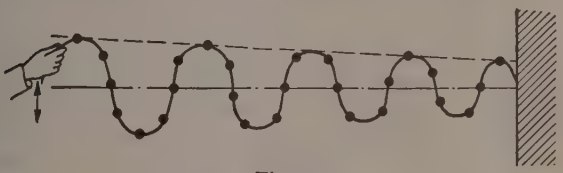


Fig. 60

place them closer together it will be found that the waves will now travel the length of the string even more easily than before.

We take advantage of the effect illustrated above in loading telephone circuits and employ coils of different inductances or place them in circuits with

different spacings, depending upon the attenuation we desire to obtain. The larger the inductance added to the line within reasonable limits or the closer they are placed together, the smaller will be the current and consequently the lower the losses of electrical energy in the line itself. The loading coils in telephone circuits are spaced at regular intervals, the spacing varying with the amount of inductance we wish to add to the circuit. In cable, for example, this explains why some loading coils are spaced approximately 1.15 miles apart and others approximately 1.66 miles apart.

Since the capacity of an open wire circuit is much less than that of a cable circuit, the reactance due to this capacity is much higher per unit of length for the open wire circuit. Therefore, it is not necessary to place loading coils so close together on the open wire circuits as it is on the cable circuits. From this we can draw the conclusion that the spacing of the coils for any type of loading is dependent upon the capacity of the telephone circuit per mile of length. We know that the capacity of a telephone circuit varies directly with the length, and this explains why it is often necessary to construct special manholes for the purpose of loading cable circuits since, if we used existing manholes, the capacity between adjacent coils would probably be either too great or too small. The exact value must be obtained or certain irregularities will exist which interfere seriously with the operation of other parts of the telephone plant. These irregularities will be discussed in other sections.

ELEMENTARY PRINCIPLES—ALTERNATING CURRENTS

SECTION II-G

BALANCE OF LINES—PHANTOM CIRCUITS

Balance of Lines

In the foregong sections we have considered those features of the telephone system required for successfully transmitting the speech energy from the talker to the listener. There are other requirements in the circuit, however, that are equally important. It is not only essential that the attenuation be kept within certain limits, but crosstalk and noise must be reduced to a minimum. This requires what is known as a high degree of balance, involving the use of transpositions and other means of preventing a transfer of energy from other circuits which may be either communication circuits or power circuits.

The first telephone lines built in this country did not have the wires "transposed." This was due mainly to the fact that the lines were short so that the little crosstalk existing was not readily noticeable. However, upon the completion of the first long open wire toll lines the effect of crosstalk became very noticeable even with all the circuits metallic. A person talking over one pair of wires could be heard distinctly on the other circuits although there was no direct connection between them. An investigation showed that this could be greatly reduced by properly transposing the telephone circuits.

In explaining the reasons for crosstalk, let us assume a typical open wire toll line and endeavor to show how the conversation over one pair of wires may be heard on another if the line is not transposed. Carrying this further we shall see why the proper kind of transpositions are necessary in order to reduce the crosstalk.

Referring to Fig. 61, we will assume that an alternating current is flowing in the circuit made up of wires 1 and 2. Assume that the current is flow-

ing for the instant in the direction indicated by the arrows in Fig. 62. We know that a current flowing through a wire sets up a magnetic field about it in circular form and at right angles to the wire. This

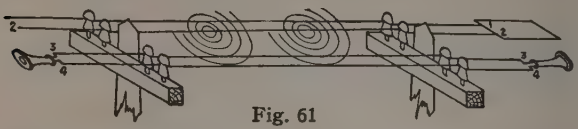


Fig. 61

field set up about wire No. 2, expanding and contracting with the rise and fall of the current, cuts conductors 3 and 4. More lines of force, however, cut conductor 3 than 4 because the former is nearer the disturbing wire. We have learned in the section on electro-magnetic inductance that when lines of force cut a conductor, a voltage is set up in the conductor so cut. This effect may be likened, therefore, to an infinite number of tiny alternating current generators, each in series with the line, those in wire 3 producing a voltage higher than the ones in wire 4. This is illustrated in Figure 62.

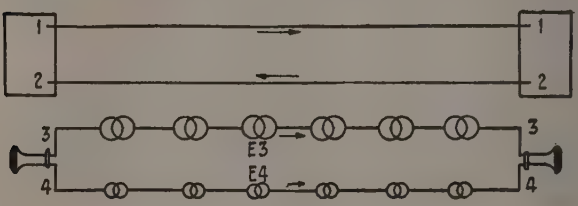


Fig. 62

Referring to Fig. 62, let us designate the sum of all the voltages induced in wire No. 3 as E_3, and the sum of those in wire No. 4 as E_4. We have shown that the voltage of each of these little generators in wire 3 is higher than that of each generator in wire 4.

Assuming the same number of generators in each, it is evident that E_3 must be greater than E_4. Since these voltages are induced from the same magnetic field they are of the same direction and consequently oppose each other when considered from the standpoint of the circuit as a whole. When two voltages oppose each other and they are of unequal magnitude, we have remaining a voltage which is equal to the difference of the two acting in the direction of the more powerful one. This voltage we will call the resultant, and in this case it is equal to $E_3 - E_4$. Let us designate this by **e**. This voltage tends to produce currents which will flow around the circuit in the direction indicated by the arrows in Figure 63, and its magnitude will be equal to **e** divided by $2Z_r$, since we know that the alternating current flowing in any series circuit is equal to the alternating voltage applied to that circuit divided by the total

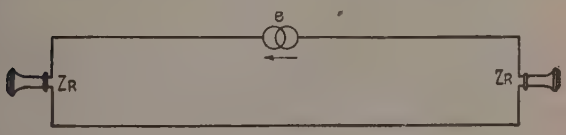


Fig. 63

impedance. The impedance of the circuit in this case is equal to the sum of the impedances of the two receivers, one at each end of the circuit and designated above as Z_r; consequently, we will have an alternating current flowing through the receiver which follows faithfully all variations of the current producing it, this current being the one flowing in line wire 2 of Figure 62. If the exposure is long enough, that is, if we have enough of these small generators in series, we can hear distinctly in the

receiver any conversation being carried on over wires 1 and 2 of Figure 62.

Wire No. 1 also sets up a small voltage in wires 3 and 4 opposite in direction to that set up by wire 2, but since wire 1 is further away, the voltage is much weaker and is easily overcome by that set up by wire 2.

This whole effect is known as electro-magnetic crosstalk, since it is based upon the fundamental theory of electro-magnetic induction. Now let us see what can be done to overcome this feature. Taking the same circuit as shown in Figure 62, suppose that for half the distance we let wire 3 take the place formerly occupied by wire 4 and wire 4 the

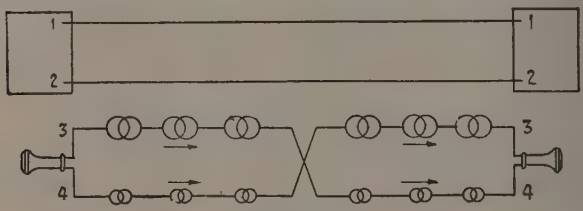


Fig. 64

place of wire 3 as shown in Figure 64. Following the same line of reasoning as before the total voltage induced in wire 3 is one-half of E_3+E_4, and the total voltage induced in wire 4 is also one-half of E_3+E_4. These voltages, as before, operate in the same direction in each wire as indicated by the arrows and the resultant voltage, in this case, will be equal to $\frac{E_3+E_4}{2}$ subtracted from $\frac{E_3+E_4}{2}$. This, of course, is equal to zero. Since there is no resultant voltage acting to force a current through the circuit, no current will flow and there will be

no crosstalk. This changing of the wires which affected this desirable result is known as a transposition. We see, therefore, that transpositions properly placed will reduce crosstalk induced from alternating currents.

We have seen in the preceding paragraphs how an alternating current causes crosstalk. Alternating voltages are also a source of crosstalk which is caused by the difference in capacity between the various wires and also between each wire and the ground setting up a difference in potential between the two wires of an adjacent circuit. This difference in potential between the two wires naturally causes a current to flow in the circuit which again results in crosstalk. Fortunately, however, this condition may also be corrected by the proper use of transpositions and all transpositions, therefore, are designed so as to neutralize as much as possible all crosstalk effects.

The above discussion brings out the importance of placing transpositions at the points indicated by the people who designed them. If not properly placed, or if omitted, crosstalk may be expected as a result. Suppose, for example, in Figure 64 above, we place the one transposition near either end of the circuit. If this is done it is evident that there will be a resultant voltage which will cause a current to flow through the circuit. In practice, transpositions are placed much oftener than once in each circuit, and if any one of them is omitted or misplaced, it will result in some combination of voltages such that crosstalk will exist. The interrelation of the transpositions is such that the omission or misplacing of any one of them will frequently unbalance many circuits on the same open wire lead.

Referring again to Figure 64, if we transpose wires 1 and 2 and leave wires 3 and 4 untransposed the same result would be obtained, that is, the crosstalk would be reduced. This is due to the fact that the current flowing in the wire nearest wires 3 and 4 is in one direction for half of the distance and in the opposite direction for the remaining half. It is easily seen that the voltages set up in wires 3 and 4 by this current would neutralize each other since they are equal and in opposite directions. In practice all the wires on a lead are transposed since each pair must be balanced with respect to every other circuit on the lead and outside circuits.

In one of the preceding paragraphs it was stated that transpositions are placed much oftener than once in each circuit. The necessity for frequent transpositions from a crosstalk standpoint arises from the fact that currents are attenuated as they flow along a circuit which results in making the induced voltages smaller in magnitude as we traverse the line in the direction of the attenuation. Thus if in Figure 62 we consider the left hand end of wires 1 and 2 as the talking end, the talking current is reduced greatly when it reaches the right hand or receiving end as explained in Section II-E on attenuation. The effect of this attenuation is to reduce the voltage of the generators in wires 3 and 4 of Figure 62 as we go from left to right, that is, the generators on the right will have a slightly lower voltage than the ones just to the left. Referring now to Figure 64 we can see that the voltages in the two sections will not exactly neutralize each other as previously stated. It is also easy to see that the longer we make the sections between transposition points, the greater will be the differ-

ence between voltages and therefore the necessity for frequent transpositions.

Noise Effects

Let us assume that wires 1 and 2 in Figure 61 are replaced by a commercial power circuit of high voltage carrying a current which is very large as compared to that in the telephone circuits. Naturally this would induce voltages in wires 3 and 4 in the same manner that the telephone currents did. These voltages, however, would be much larger than those induced by the telephone currents since the power current is many times greater than the telephone current. From this we can see the necessity of keeping our telephone circuits as far as possible from all power circuits in order to avoid these so-called "noise effects."

Phantom Circuits

A phantom circuit is a telephone path built up on two existing circuits in such a manner that electrical energy may be transmitted simultaneously over both the side circuits and the phantom without the energy in any one path interfering with that in any other. In order to create a phantom it is necessary to employ some device in the side circuits that will result in a small transmission loss to them and at the same time permit the phantom circuit to operate properly. We could create a phantom by the method illustrated in Figure 65 where a resistance is indicated as being bridged across each terminal of two physical circuits. A wire brought out from the middle point of each of these resistances would form a phantom circuit that would operate satisfactorily, provided the resistances were so low as to offer very

little opposition to the flow of current in the phantom circuit, but if they were low we would have a low resistance shunt directly across each end of the physical circuits resulting in a very large transmis-

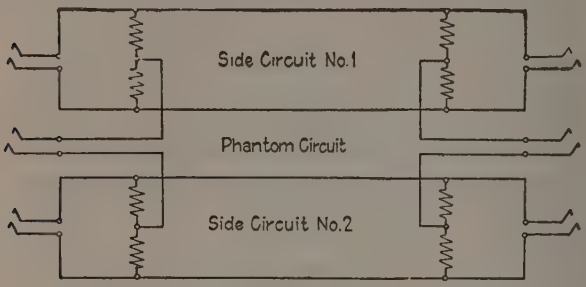


Fig. 65

sion loss to these circuits. This method therefore can not be employed without introducing transmission losses in excess of those which we ordinarily allow.

But now suppose we substitute transformers for these resistances, these transformers having the winding on the line side divided into two exactly equal parts, that is, having the two halves of the winding balanced. If a wire is connected to the middle point of this line winding at each of the transformers, as indicated in Figure 66, we will again have a satisfactory phantom circuit. The current flowing in one side of the phantom circuit enters the mid-point of the balanced winding of the transformer and divides into two equal parts, each part flowing over one wire of the side circuit in the same direction. This flow of current in the phantom circuit is indicated by the arrows, and it will be noticed that it flows in opposite directions through

the two halves of the transformer; consequently the magnetic field set up by the current flowing through one-half of the winding is exactly opposite in direction to the magnetic field set up by the current

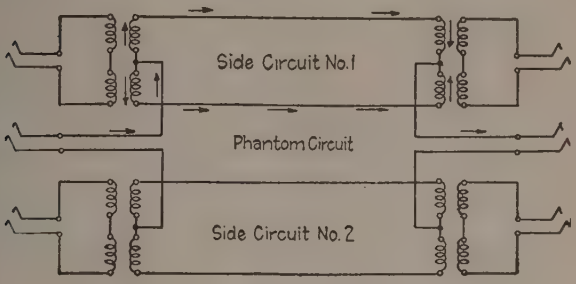


Fig. 66

flowing through the other half. These two magnetic fields, being of the same magnitude but opposite in direction, neutralize each other so that practically no lines of force remain in the core of the transformer. Without lines of force it is impossible, of course, to induce a voltage in the other winding and therefore we have no flow of current in the drop side of the transformers.

In addition, these two halves of the winding offer a very small resistance to the flow of current in the phantom circuit. Therefore, we have obtained the necessary features to insure successful operation of the phantom. The question now is will the side circuits operate with a low transmission loss and with no interference from or to the phantom circuit?

If an alternating voltage is placed across the drop side of the coil in side circuit No. 1, as indicated in Figure 67, the current produced will flow in the direction shown by the arrows. This current flows

in the same direction throughout both halves of the drop winding of the transformer and therefore sets up a magnetic field in the core. The lines of force of this magnetic field link the winding of the line

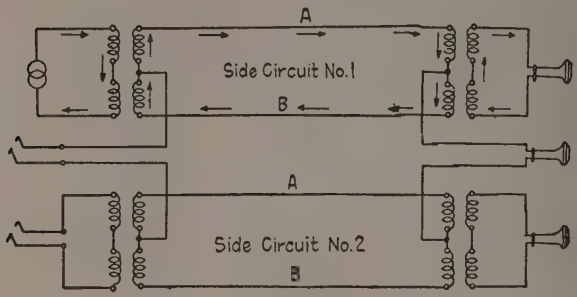


Fig. 67

side of the transformer and induce in each half of it voltages which aid each other. The sum of these voltages causes a current to flow in the line and, through the line winding of the transformer at the other end of the circuit. This current again induces a voltage in the drop winding of this second transformer which causes a current to flow through the receiver.

The current flow in this side circuit is indicated by the arrows in Figure 67 and is of the same magnitude in both sides of the circuit. Assume that the circuit is perfectly balanced, that is, the resistance of it from the mid-point of one transformer through line wire **A** to the mid-point of the other transformer is exactly the same as that of the other path through line wire **B.** We know from Ohm's Law that the voltage across any two points in a circuit is equal to the current flowing through that circuit multiplied by its resistance. Since, as stated

above, the current flowing in both sides of the line is equal, and since the resistance of each of the paths is equal, it is evident that the voltages across each of these paths measured from the mid-point of the transformers must also be equal. We therefore have two equal voltages opposing each other, and consequently no current will flow in the phantom circuit.

The transformers in the side circuits cause a very small transmission loss to these circuits, and, as pointed out above, an even smaller loss to the phantom circuit. There is, as shown, no interference between the side and phantom circuits provided the former are perfectly balanced. We now have three satisfactory telephone paths over two pairs of wires. This feature is employed on almost all toll lines and on toll cables, and the third path so derived is called the phantom circuit. The transformers used to derive this phantom are commonly called phantom coils or phantom repeating coils.

We note throughout the above discussion of the operation of the phantom circuits that in all cases we have made the assumption that the two halves of each side circuit are perfectly balanced. Suppose that for some reason or other one of these side circuits now becomes unbalanced, as for example if a high resistance sleeve is cut in the line wire **A** of side circuit No. 1 shown in Figure 68. The phantom circuit current which flows in side circuit No. 1 will not split equally between wires **A** and **B.**

We have seen that when the currents in wires **A** and **B** are equal the magnetic fields they set up around the cores of the phantom repeating coils neutralize each other so that no currents are induced in the drop sides of the repeating coils.

Since the currents are unequal, however, this balance condition will not exist and induced currents will flow in the drop sides of the repeating coils,

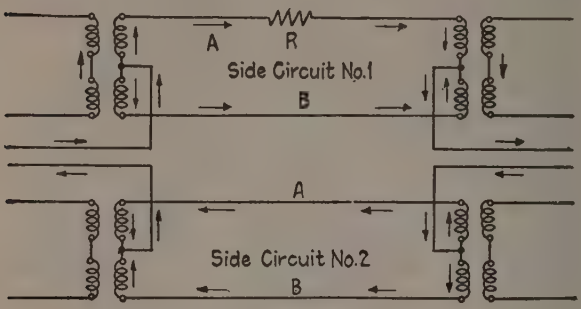


Fig. 68

of side circuit No. 1, causing crosstalk. This is known as phantom to side crosstalk.

The above brings out in a very brief way the special importance of securing a very high degree of balance of phantom circuits or of circuits which are to be phantomed. A shunt unbalance, such as a broken insulator, which renders the leakage to ground of one side of the line higher than that of the other side will have a similar effect and will also produce phantom to side crosstalk.

Some of the most common sources of series unbalances are bad joints in wires, high resistances in test connectors, poor connections in cable terminals, reversal of one winding of a side circuit loading coil in one side circuit of the phantom and unequal inductances added to the phantom circuit by side circuit loading coils. The most common sources of shunt unbalances are contact of line wires with trees, defective, broken or cracked insulators, espe-

cially on creosoted pole lines where the pole forms a fairly good conductor to ground, contact of line wires with crossarms, guy wires or other wires falling across the line, leakage at open space cutouts due to dirty carbon blocks, capacity or insulation unbalances to ground in cable circuits, and capacity unbalances due to irregularities in transpositions.

In toll cable circuits we often have a small difference in capacity between the wires of the circuits which make up a quad or phantom circuit and the ground. This difference in capacity is commonly called capacity unbalance and is due to the fact that it is impossible in commercial manufacture to strand the wires with sufficient precision to eliminate entirely these small differences in capacity. Since they exist, however, we must correct for them or phantom to side and side to side crosstalk will result. This correction is made when the cable is installed by means of what are called capacity unbalance tests. These tests consist merely of measuring the capacity unbalances of each quad of wires in both directions and splicing them together so that the unbalances tend to neutralize each other. If an error is made in a capacity unbalance test splice, it is quite possible that the unbalances will be increased rather than diminished, and for this reason great care must be taken in all such work.

ELEMENTARY PRINCIPLES—
ALTERNATING CURRENTS

SECTION II-H

AMPLIFICATION OF ALTERNATING CURRENTS
VACUUM TUBES

Amplification of Alternating Currents—Vacuum Tubes

When the attenuation of a telephone circuit becomes too great, due to the length of the circuit or other reasons, it is often found that the use of amplifiers will effect the necessary reduction in attenuation more cheaply than would loading or larger gauge conductors. An amplifier causes an effect that is just the reverse of attenuation; i.e., it delivers more electrical energy to the line than it received from it. Where does this additional energy come from?

If we take the electrical energy at any point in a telephone line, pass it through some sort of a device and give it back to the line again to continue its journey, much larger than when it was received, we may say that we have amplified it. Since an alternating current is the medium that transfers the electrical energy from one end of the circuit to the other, if we amplify it we also are increasing the electrical energy at the same point in the line. It is, of course, impossible to deliver more to the line at any one point than is received from the line at that point, unless some external source of energy is added. This is just what we do in amplifying telephone currents; we add an external source of energy to the small amount received at the amplifying station.

The simplest and first form of amplifier consisted practically of the coils and magnet of a receiver and the carbon button of a transmitter so associated that the vibrations of the receiver diaphragm caused by the feeble incoming current were transmitted mechanically to the carbon button of the transmitter. A fairly large current flowing through the trans-

mitter button and the primary of an induction coil varied in response to the variations in the receiver diaphragm caused by the feeble incoming currents. This new current flowing through the primary winding of the induction coil induced an alternating current in the secondary of the induction coil which followed closely all variations of the feeble incoming current in the telephone receiver coils. It was

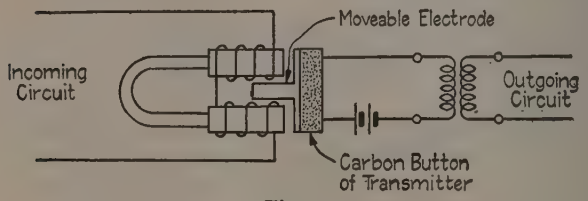


Fig. 69

much larger, however, since additional energy was introduced by the battery in the transmitter circuit. This device is illustrated in Figure 69. Amplifiers employing this principle were actually employed on commercial telephone circuits before the advent of the vacuum tube.

The development of the vacuum tube opened up an entirely new field in the use of amplifiers and these have now supplanted the old mechanical device of the associated receiver and transmitter. Since the vacuum tube is the essential part of all amplifiers used in the telephone plant today, a brief description of the way it works will be of interest.

Primarily a vacuum tube consists of a filament, a grid and a plate enclosed in a glass bulb from which the air has been exhausted. A simplified sketch of a typical vacuum tube is shown in Figure 70.

In operation the filament is heated by a current flowing through it from a battery connected across its terminals. This battery is known as the "A" battery and is employed only for the purpose of heating the filament. If this could be heated in any

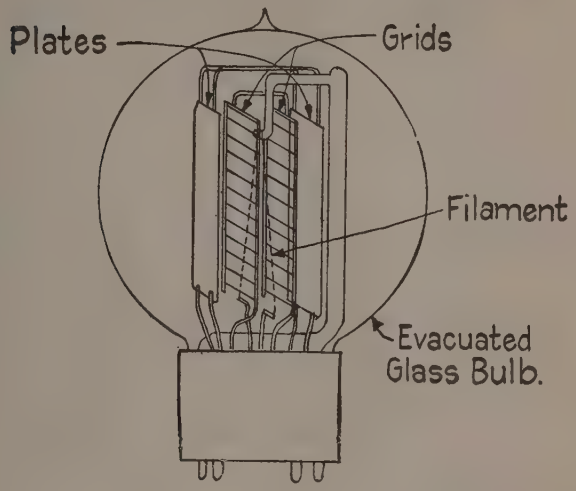


Fig. 70

other practical manner, the use of the "A" battery could be discontinued. A battery known as the "B" battery has its positive terminal connected to the plate and its negative terminal connected to one side of the filament. Ordinarily this battery is placed in series with the primary winding of a transformer, as shown in Figure 71. The input circuit is connected between the grid and the same side of the filament to which one terminal of the "B" battery is connected. This is also shown in Figure

71, which gives the complete circuit of a vacuum tube used as an amplifier.

When the filament of a vacuum tube is heated it has the peculiar property of continually throwing

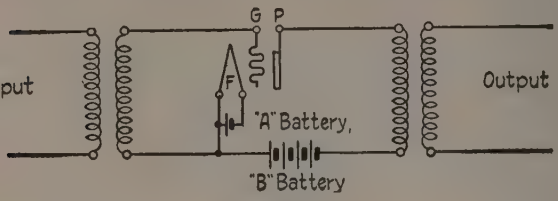


Fig. 71

off in all directions very tiny particles of negative electricity called electrons. A simple plate circuit as shown in Figure 71 consists of the "B" battery, the primary winding of the transformer, the plate of the tube, and the space between the filament and the plate. When the filament is cold no electrons are thrown off and the circuit is open. When, however, the filament is heated the electrons are thrown off and flow across the space between the filament and plate. This electron flow is an electric current. If the potentials of the "B" and "A" batteries are constant and the grid voltage does not vary, then this current flows continuously in the same direction, that is in the direction from the filament to the plate, with a uniform magnitude and therefore is a constant direct current. The complete circuit in which this current flows is the plate circuit described above and shown in Figure 71.

Between the filament and the plate we have interposed something which may be likened to a window shutter, the vanes of which are all connected to and actuated by one motion of a rod extending up the

center of the shutter. If some external force is applied to this rod in such a manner as to move it up and down, thereby closing or opening the spaces through which these electrons must pass, it is evident that the number of them which will go through depends upon the size of the openings. We have already seen how the flow of these electrons sets up a current in the electrical plate circuit and if their flow is impeded or aided by the closing or opening of the shutter, corresponding variations will take place in the current.

This is exactly what happens in the vacuum tube. We have seen in Figure 71 that the input circuit carrying the feeble incoming current is connected between filament and grid. This current sets up a voltage equal to the potential drop between the filament and grid, this voltage varying directly in accordance with the variations of the incoming current. As this voltage on the grid changes from a positive to a negative value, it attracts or repels some of the small negative electrons which must flow through the grid to the plate. When it attracts the electrons more of them go through, but when it repels them it reduces the number that flow through to the plate. This is similar to the action of the shutter explained above and causes the variations of current in the plate circuit to follow exactly the variations of the incoming current.

This current in the plate circuit, however, is much larger than that coming in from the line due to the additional energy added to the circuit by the introduction of the "B" battery. From the secondary of the transformer it flows out on the line much larger than when it entered the amplifier and con-

sequently the attenuation of the entire circuit has been considerably reduced.

This briefly is the action of the vacuum tube when used as an amplifier and this principle has been applied to the telephone repeaters which are now in almost general use throughout the telephone plant. Many variations of the simple circuit shown in Figure 71 are used in order to apply this device efficiently to our telephone circuits and the principles governing the operation of these circuits will be covered in the following section under the heading "Telephone Repeaters."

In practice an additional battery known as the "C" battery is connected in series with the grid circuit with its negative pole towards the grid. The purpose of this battery is to maintain the grid negative with respect to the filament and its action will be covered in considerable detail in the section on "Telephone Repeaters."

ELEMENTARY PRINCIPLES— ALTERNATING CURRENTS

SECTION II

APPENDIX A

CURVES

Graphical Representation of Numbers or Quantities

This simple explanation of curves is given to acquaint the reader with an idea of the graphical method of representing the relation of two factors (either or both of which may be changing) that affect one another. The various voltage, current and sound waves discussed in the previous sections can be more clearly understood by means of graphical representation. The following description covers a type of curve which is found very generally in alternating current work. However, we should understand that the description is very elementary and brief. For a more complete discussion on graphical representation of numbers or quantities the reader is referred to text books on the subject.

Assume that we have a straight line and a fixed point 0 be taken on this line as in Fig. 72.

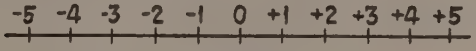


Fig. 72

If now we adopt any length as a unit of distance, this unit can be laid off in succession on the line, to either side of point 0. Other points are thus obtained on this line, whose distance from 0 are 1, 2, 3, - - -, etc., times the unit distance.

Thus a point 5 units from 0 may be taken to represent the number 5. This point may be located either to the right or left of 0. In order to distinguish the location of a point to the right of 0 from the location of a point to the left of 0, all points to the right are considered as positive and all points to the left, negative. Therefore, a point 5 units to

the right of 0 represents the number + 5 or 5, the plus sign ordinarily being omitted, and the point 5 units to the left of 0 represents — 5, the negative sign never being omitted.

Exactly the same procedure may be applied if we have a vertical line, assuming some fixed point on this line, we can lay off in succession any unit of distance above and below the fixed point, as shown in Fig. 73.

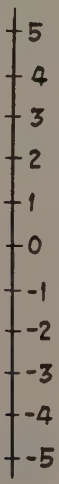


Fig. 73

In the case of a vertical line, it is customary to assume that the points above 0 are positive and the points below 0 are negative.

Assume now that Fig. 2 is superimposed or placed on top of Fig. 1 and the two fixed points 0 are brought together so that they coincide, and the lines or axes are at right angles. This will give us Fig. 74.

The above lines or axes can now be used to show and compare graphically any variations or changes in conditions. Thus we may use these axes to

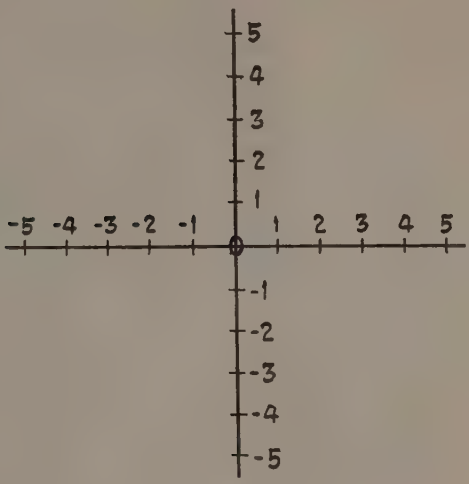


Fig. 74

record the variations in temperature on a certain day on which the hourly temperature record was as follows:

1 A.M.	4°	9 A.M.	6°	5 P.M.	16°
2 " "	4°	10 " "	10°	6 " "	12°
3 " "	2°	11 " "	14°	7 " "	10°
4 " "	0°	12 M	18°	8 " "	8°
5 " "	—2°	1 P.M.	20°	9 " "	6°
6 " "	—2°	2 " "	21°	10 " "	6°
7 " "	0°	3 " "	21°	11 " "	4°
8 " "	2°	4 " "	19°	12 M	4°

Using paper ruled in small squares (cross section paper), we draw a horizontal line, called the horizontal axis, and on this line let the distance between

the vertical lines represent a unit of time or one hour. Perpendicular to the horizontal axis we draw the vertical axis and on it let the distance between the horizontal lines represent one degree of temperature. In doing this we are representing a unit of time by a unit of distance, and a unit of temperature by a unit of distance. This is shown in Fig. 75.

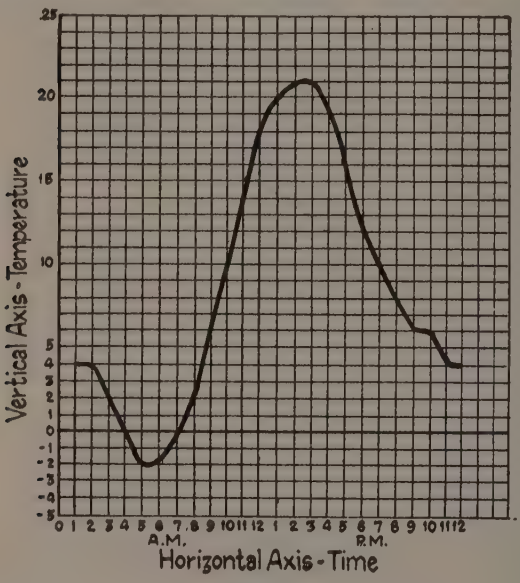


Fig. 75

In this figure the space to the left of the vertical line is not used. The space below the horizontal line, however, is used to represent negative temperatures, or temperatures below zero degrees. Fig. 4, therefore, shows graphically the temperature variations recorded on the chart. The advantage of plotting this record is that the changes in

temperature on different days can be more readily compared.

In plotting alternating current waves, exactly the same procedure is gone thru. The horizontal axis is used to represent time and is divided off into units, each unit representing a unit of time. The vertical line is divided into units of current. This is shown in Fig. 76.

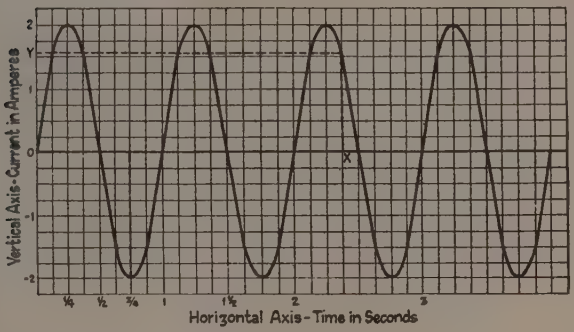


Fig. 76

On these axes, an alternating current wave is drawn. The curve shows that it requires ¼ second for the current to reach a maximum value of 2 amperes in the positive direction and that it requires ¼ second for it to decrease from this value to zero. It should be noted that during the first ½ second the current flows only in the positive direction, increasing from zero value to maximum value and decreasing to zero again without changing its direction of flow. Thus, at the end of ½ second the current has reached a value of zero. From this point the current again starts to increase, but in the opposite direction as is shown by the

curve being below the horizontal axis. It again requires ¼ second for the current to reach the maximum value of 2 amperes, and at the end of 1 second the current is zero. This completes one cycle of a current of a frequency of one cycle per second. Currents of other frequencies are plotted in the same general manner.

The amount of current flowing at any instant can be found by drawing a vertical line from any point on the horizontal axis to the curve, and then drawing a horizontal line from this point on the curve to the vertical axis. Thus at any time **X** we draw a vertical line from the horizontal axis to the curve and from the point where this line intersects the curve, we draw a horizontal line to the vertical axis, we then can read on this axis the amount of current flowing at the instant of time represented by **X.** This is shown in Fig. 76.

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